Using the Biological Condition Gradient to Develop Protective Biological Thresholds for Diverse Stream Types in Minnesota

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National Water Quality Monitoring Council Webinar Series

**MINNESOTA POLLUTION CONTROL AGENCY**

Aquatic Life Protection Objectives

Develop biological goals that satisfy:

- Federal regulations → "*To restore and maintain the chemical, physical, and biological integrity of the Nation's waters*" and "*...water quality which provides for the protection and propagation of fish, shellfish, and wildlife...*"
- Minnesota state rules → "*The quality of...surface waters shall be such as to permit the propagation and maintenance of a healthy community of...aquatic biota, and their habitats...*"
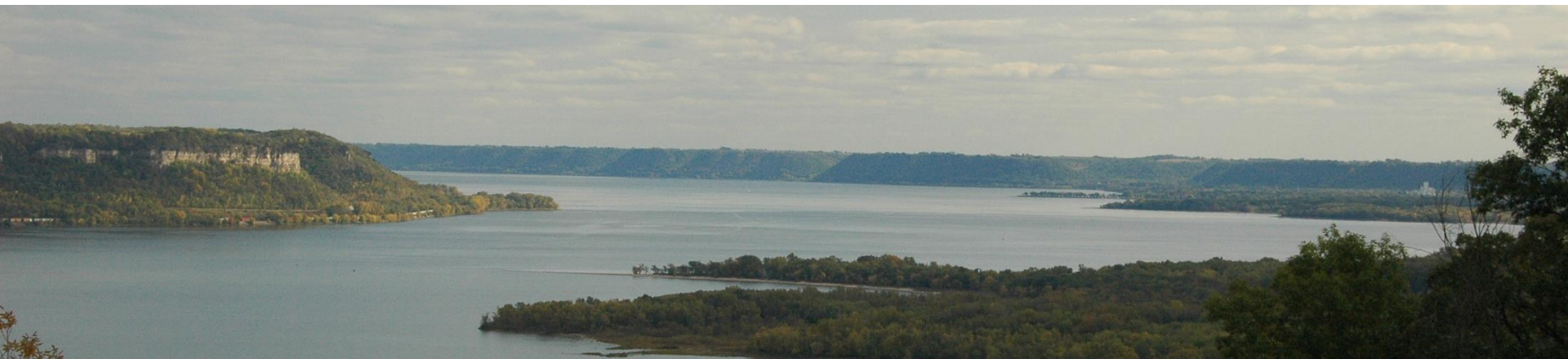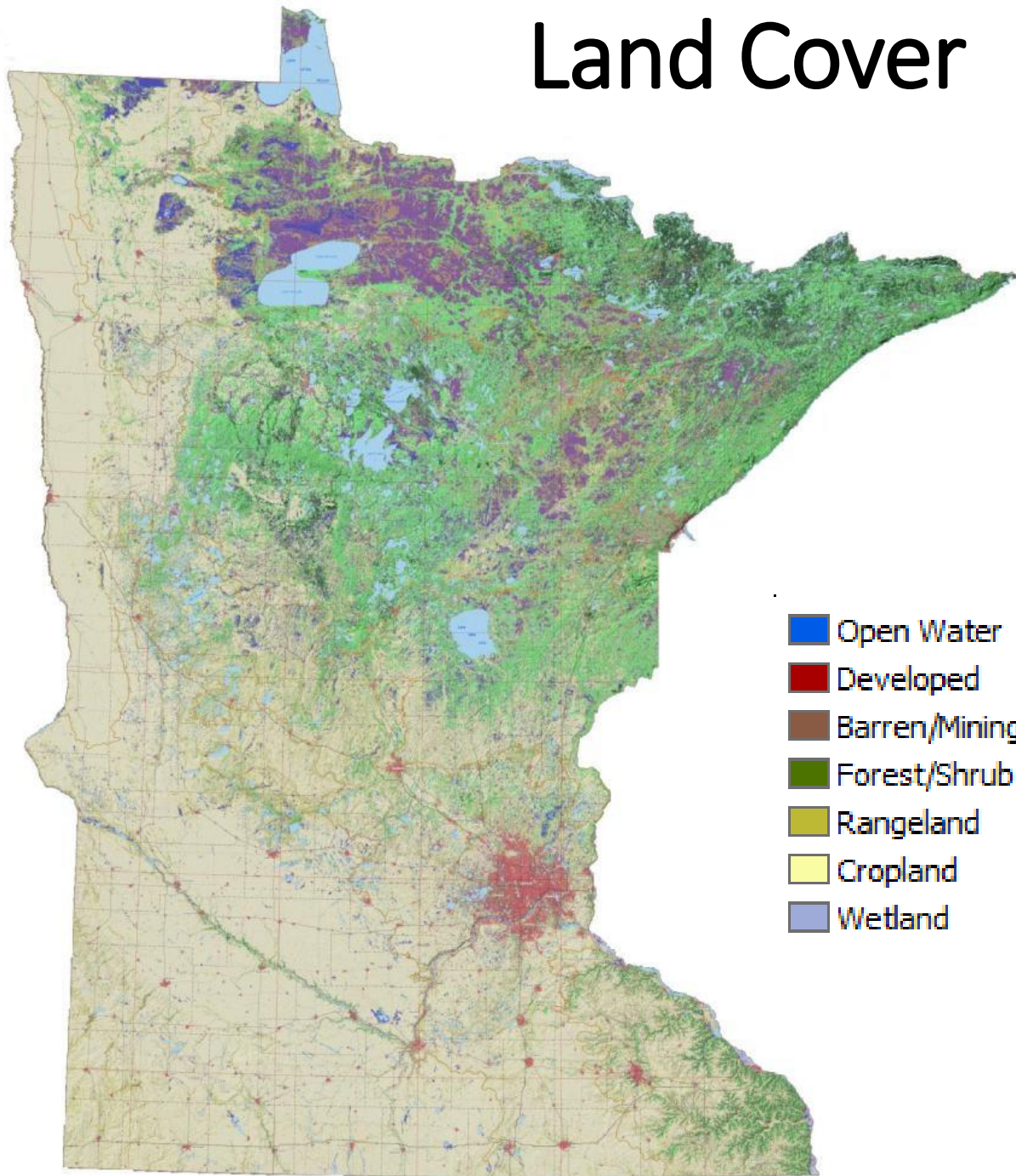
Presettlement Vegetation
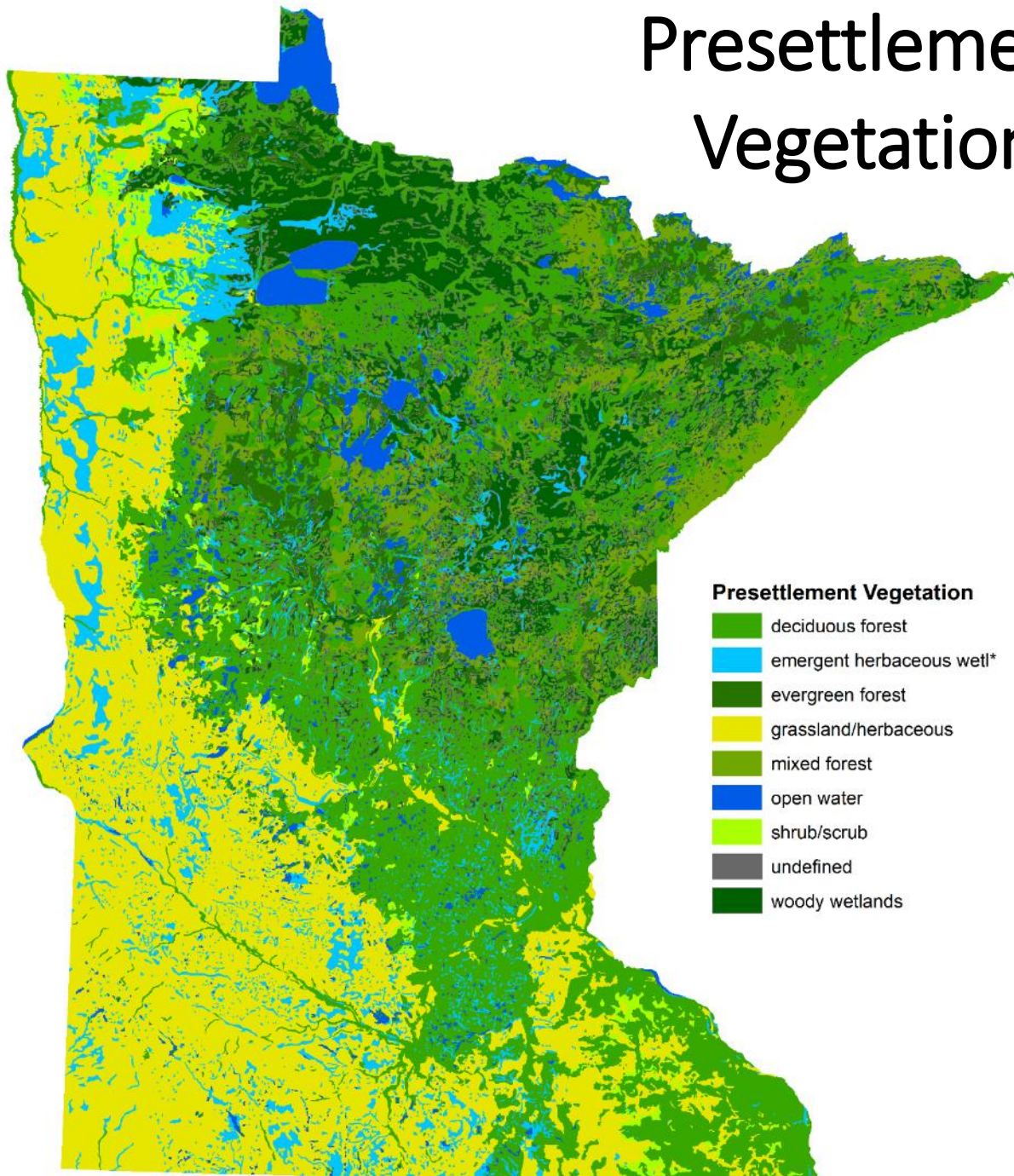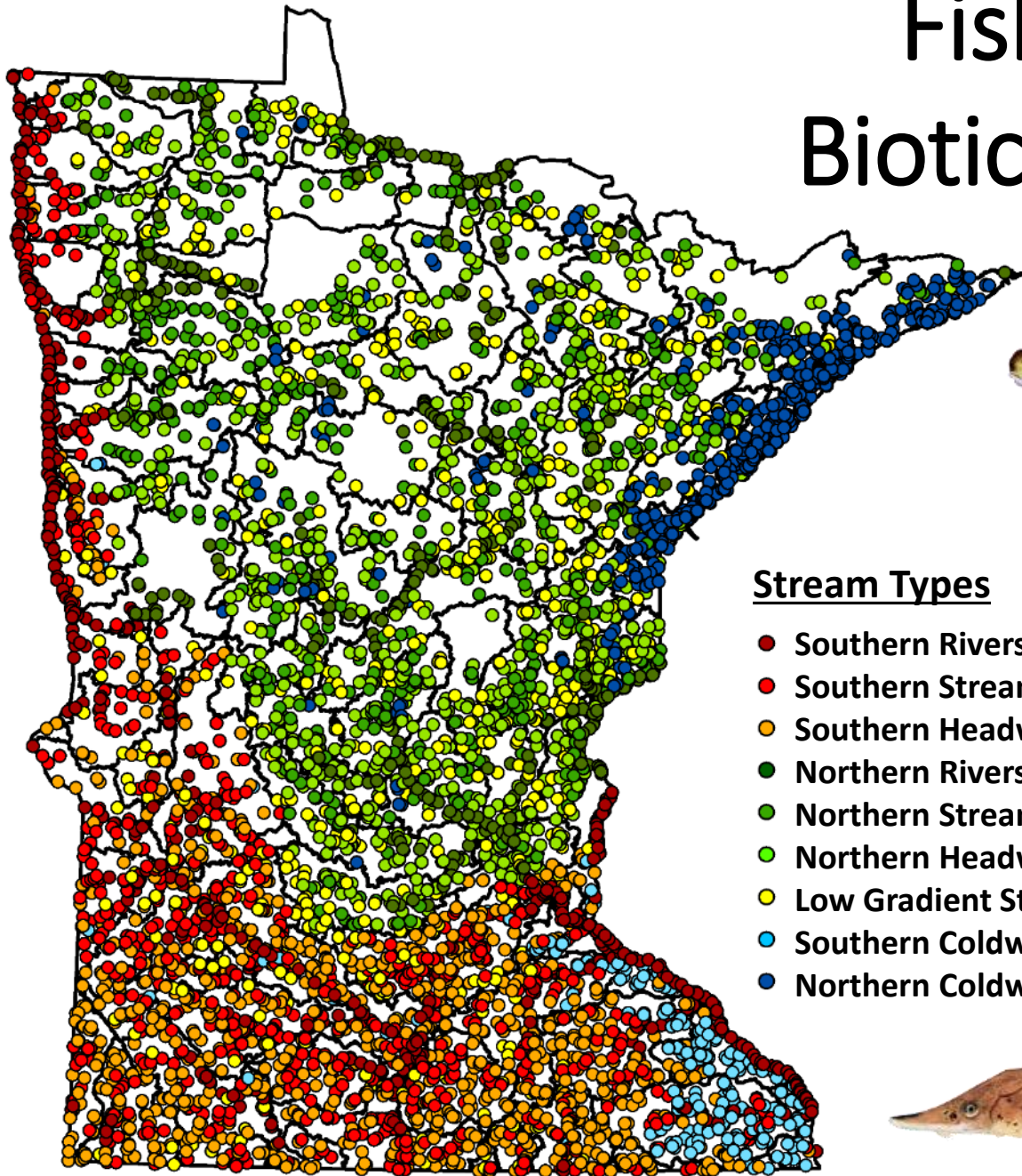

Presettlement Vegetation

- deciduous forest
- emergent herbaceous wetl*
- evergreen forest
- grassland/herbaceous
- mixed forest
- open water
- shrub/scrub
- undefined
- woody wetlands

Land Cover

Legend:

- ▇ Open Water
- ▇ Developed
- ▇ Barren/Mining
- ▇ Forest/Shrub
- ▇ Rangeland
- ▇ Cropland
- ▇ Wetland

Fish Indices of Biotic Integrity (IBI)

Stream Types

- Southern Rivers
- Southern Streams
- Southern Headwaters
- Northern Rivers
- Northern Streams
- Northern Headwaters
- Low Gradient Streams
- Southern Coldwater
- Northern Coldwater

Indices of Biotic Integrity (IBI)
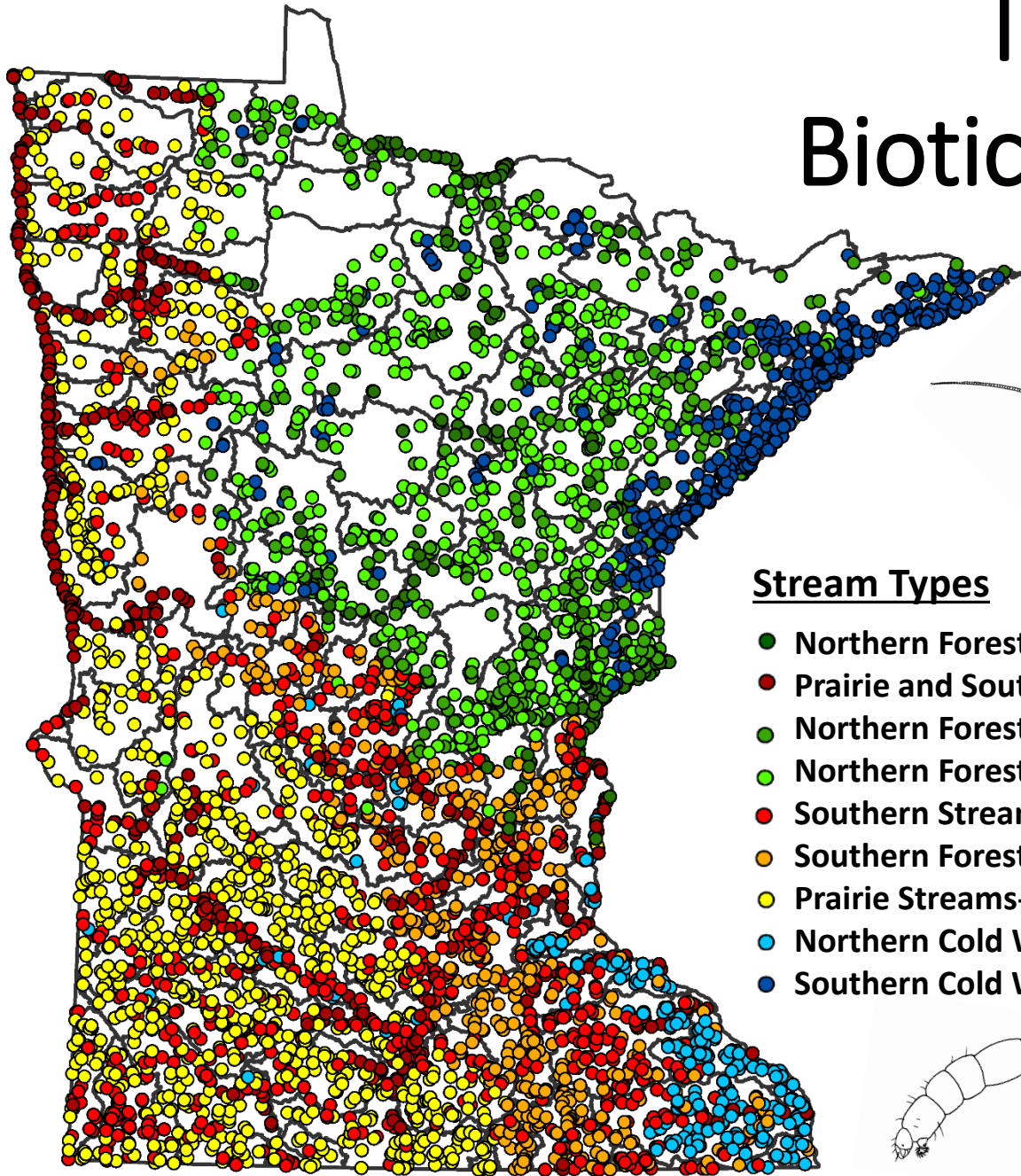
Stream Types

- Northern Forest Rivers
- Prairie and Southern Forest Rivers
- Northern Forest Streams-High Gradient
- Northern Forest Streams-Low Gradient
- Southern Streams-High Gradient
- Southern Forest Streams-Low Gradient
- Prairie Streams-Low Gradient
- Northern Cold Waters
- Southern Cold Waters
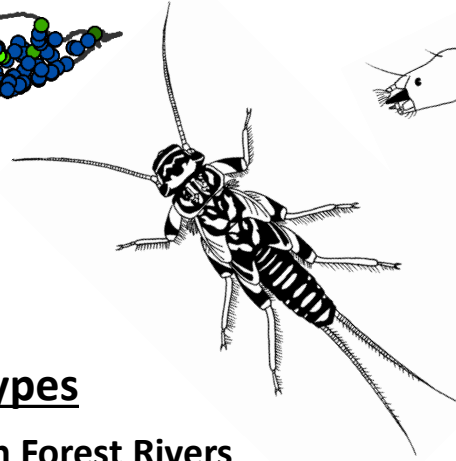
Field Sampling

Sorting and ID

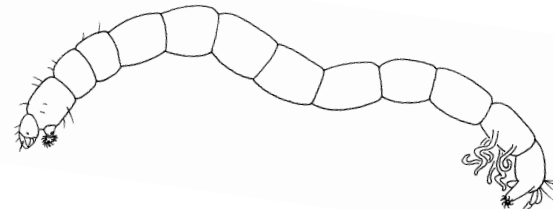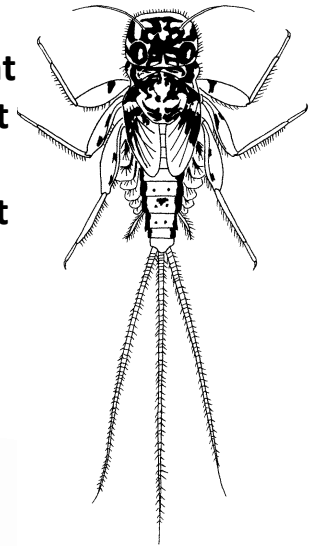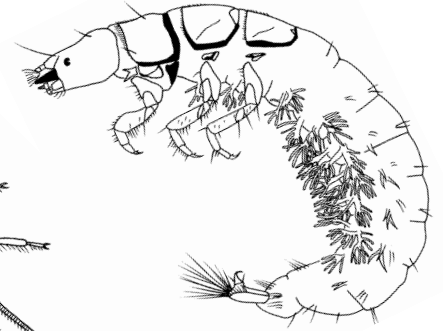**Raw Biological Data**

CommonName	Number
creek chub	78
longnose dace	50
fathead minnow	48
golden redhorse	30
common shiner	28
sand shiner	23
spotfin shiner	14
bigmouth shiner	11
common carp	10
white sucker	7
hornyhead chub	5
johnny darter	5
northern pike	4
rock bass	4
…	…

Metrics

Metric	MetricValue
Total number of fish	334
Total number of species	26
Number of Darter species	2
Number of Gravel-spawning species	9
Number of Round-bodied Sucker species	3
Percent Exotic species	3.0
Percent Minnows	80.2
Percent Piscivorous indivuals	3.3
Percent Sensitive individuals	18.6
Percent Benthic Insectivore individuals	30.5

Assessment Decision

Index of Biotic Integrity Score = 32

Indices of Biotic Integrity (IBI)
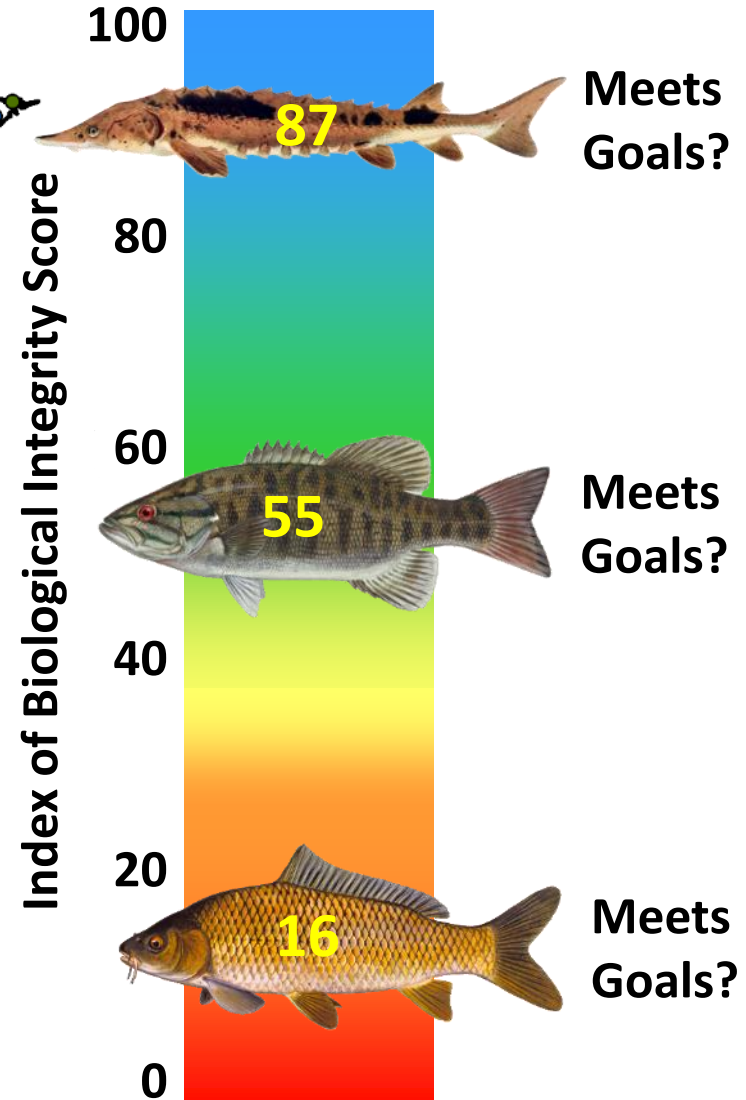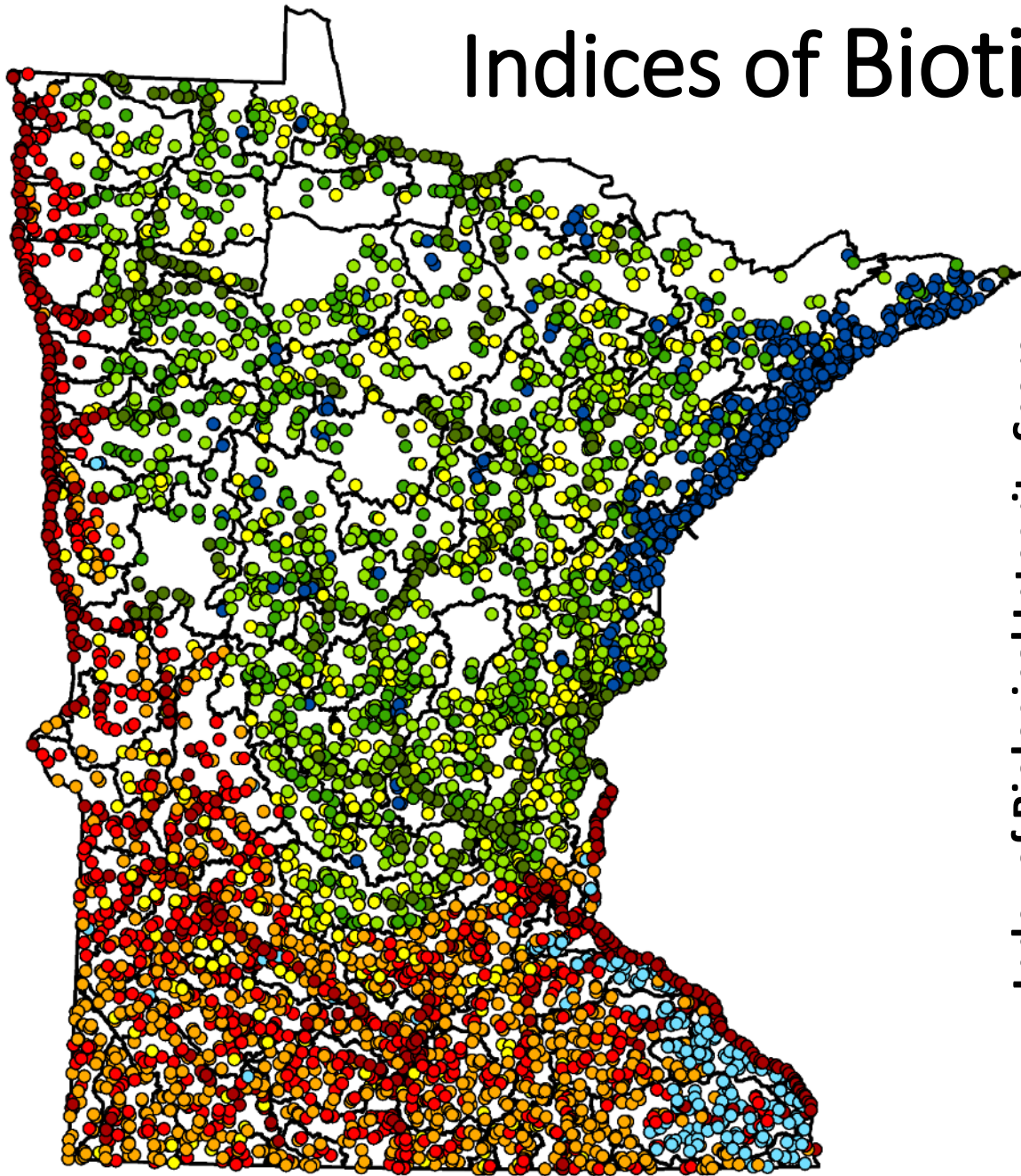
Reference Condition

- Human Disturbance Score (HDS) used to select reference sites (HDS ≥ 61)

HDS Metric	Scale	Primary Metric or Adjustment	Possible Points
Number of animal units (per km^2)	watershed	primary	10
Percent agricultural land use	watershed	primary	10
Number of point sources (per km^2)	watershed	primary	10
Percent impervious surface	watershed	primary	10
Percent channelized stream	watershed	primary	10
Degree of channelization at site	reach	primary	10
Percent disturbed riparian habitat	watershed	primary	10
Condition of riparian zone	reach	primary	10
Number of feedlots (per km^2)	watershed	adjustment	-1
Percent agricultural land use on >3% slope	watershed	adjustment	-1
Number of road crossings (per km^2)	watershed	adjustment	-1 or 1
Percent agricultural land use in 100m buffer	watershed	adjustment	-1
Feedlot adjacent to site	reach (proximity)	adjustment	-1
Point source adjacent to site	reach (proximity)	adjustment	-1
Urban land use adjacent to site	reach (proximity)	adjustment	-1
TOTAL			80

80

60

40

20

0

HDS
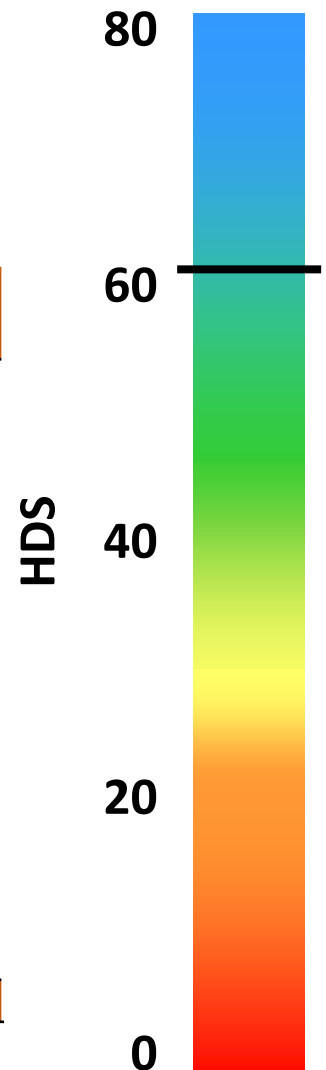
Minnesota Reference Sites
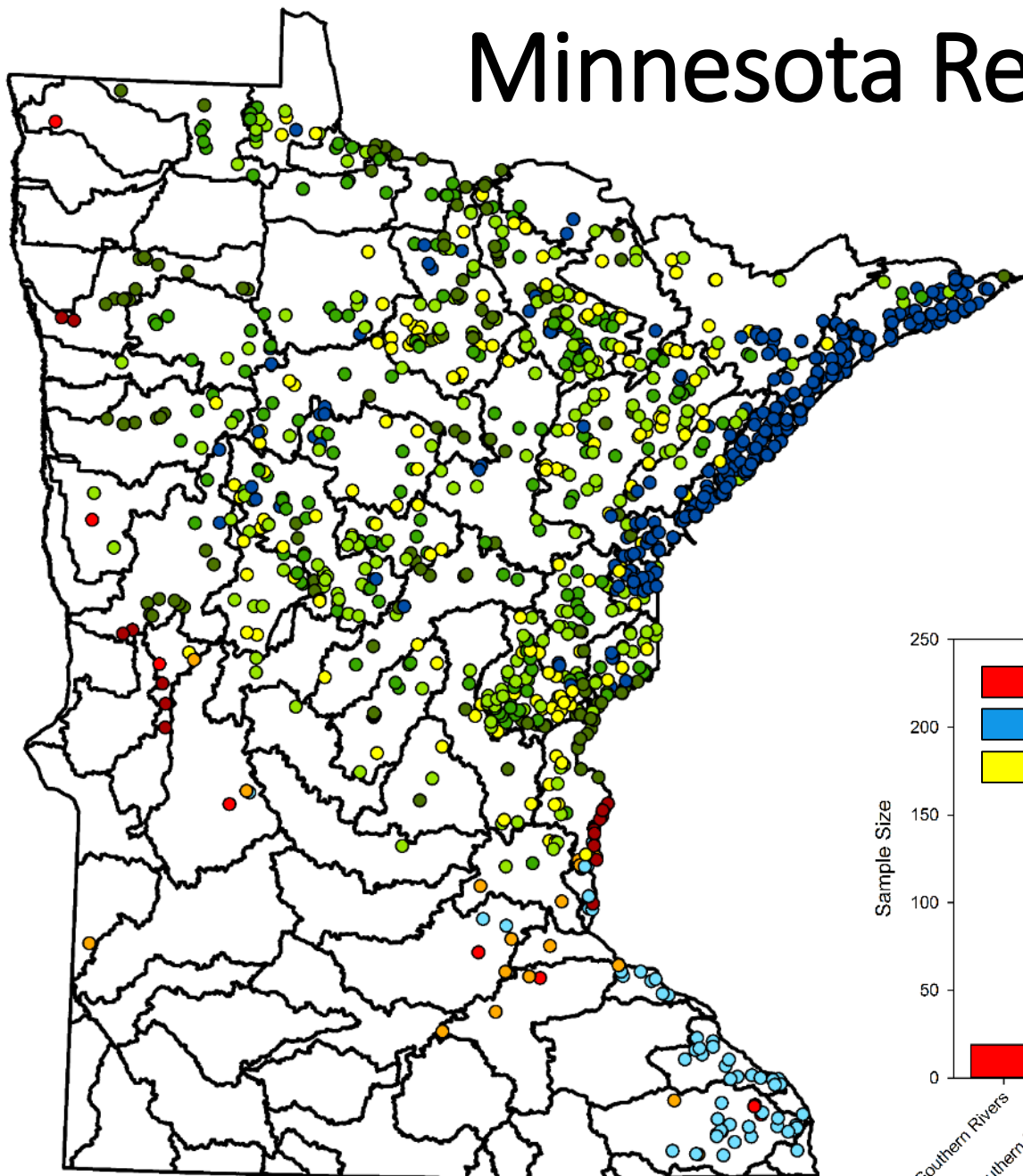
Stream Types

- Southern Rivers
- Southern Streams
- Southern Headwaters
- Northern Rivers
- Northern Streams
- Northern Headwaters
- Low Gradient Streams
- Southern Coldwater
- Northern Coldwater

South
North
Statewide
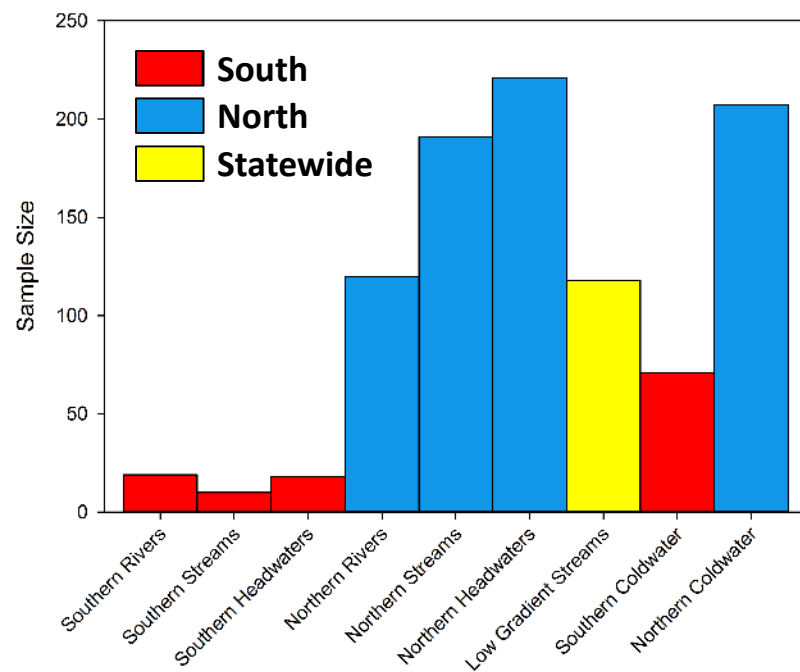
Sample Size and Statistic Estimation
25th Percentile Reference Condition
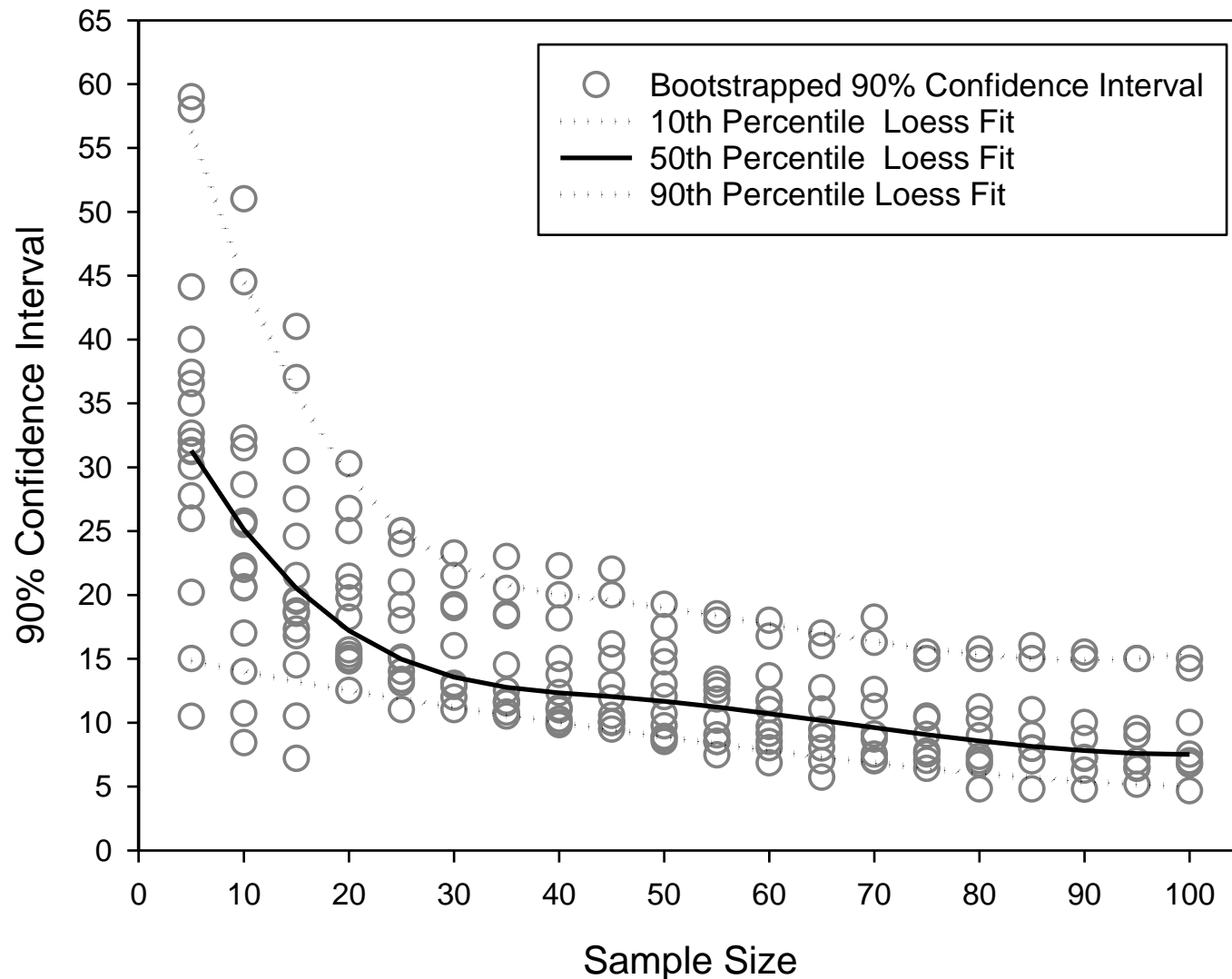
Reference Site Distributions
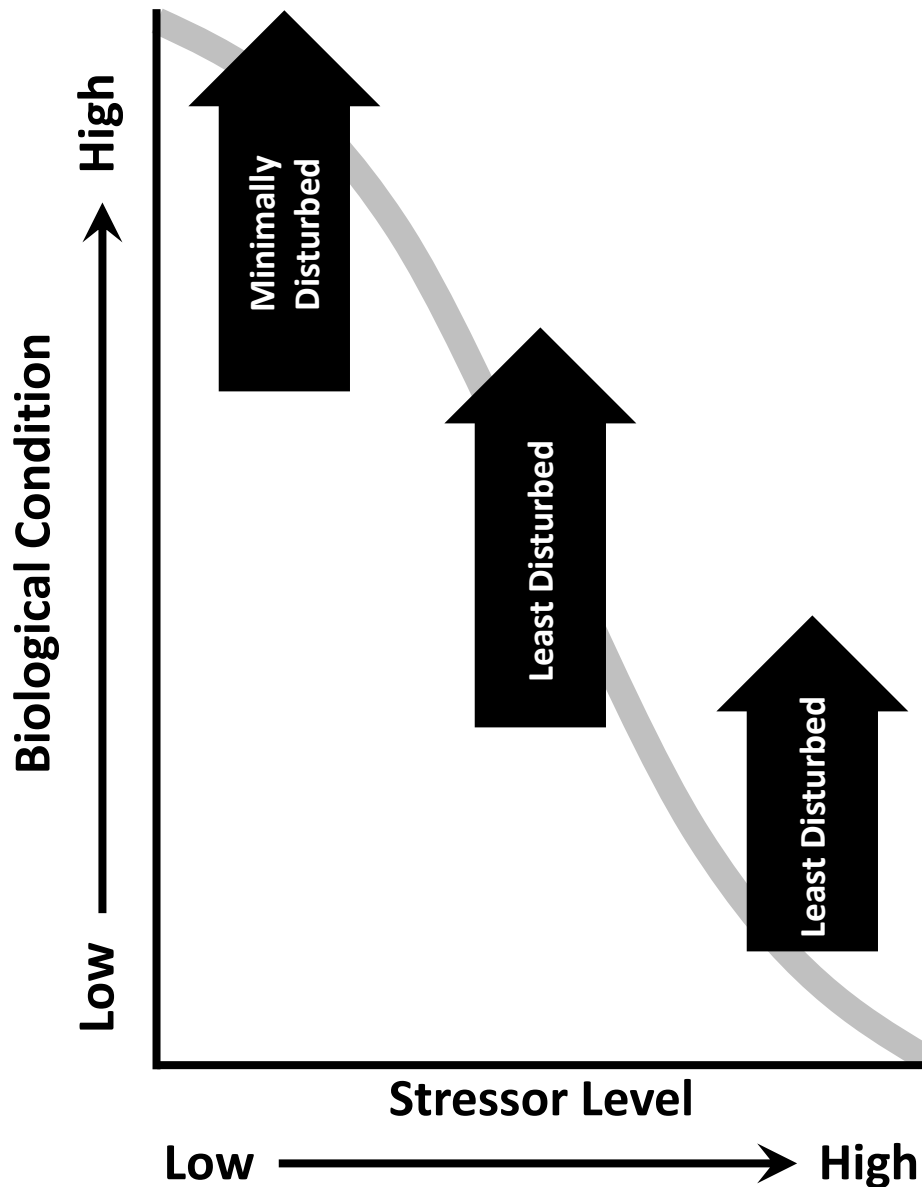
- Biological condition can differ between stream types (stressors correlated with natural gradients)

- Potential for different protection levels when setting goals

- Can be addressed using different reference site criteria and other methods

Modified from: Stoddard et al. (2006) *Ecological Applications* 16: 1267-1276.

The Biological Condition Gradient

Biological Condition (High → Low)

Level of Stressors (Low → High)

1 — Natural structural, functional, and taxonomic integrity is preserved

2 — Structure & function similar to natural community with some additional taxa & biomass; ecosystem level functions are fully maintained

3 — Evident changes in structure due to loss of some rare native taxa; shifts in relative abundance; ecosystem level functions fully maintained

4 — Moderate changes in structure due to replacement of sensitive ubiquitous taxa by more tolerant taxa; ecosystem functions largely maintained

5 — Sensitive taxa markedly diminished; conspicuously unbalanced distribution of major taxonomic groups; ecosystem function shows reduced complexity & redundancy

6 — Extreme changes in structure and ecosystem function; wholesale changes in taxonomic composition; extreme alterations from normal densities

Low — Watershed, habitat, flow regime and water chemistry as naturally occurs

High — Chemistry, habitat, and/or flow regime severely altered from natural conditions

- Framework for interpreting biological response to anthropogenic stress
- Based on combination of ecological theory and empirical data
- Supports development of biological goals
- Communicates meaning of biological goals to public and policy makers

Davies and Jackson (2006) *Ecological Applications* 16: 1251-1266.
Bouchard et al. (2016) *Environmental Monitoring and Assessment* 188(3): 1-26.
Gerritsen et al. (2017) *Freshwater Science* 36(2): 427-451.

BCG Development Process

- Classification
- Identify stressor gradient
- Workshop:
  - Identify attributes and their metrics
  - Assign sites to levels of BCG
  - Develop rules for assigning sites (decision criteria)
- Develop model(s) for automated replication of panel decisions
- Test and iterate

BCG Calibration

Step 1
Assemble data

Step 2
Analyze and prepare data

Identify expert panel

Step 3
Convene expert panel

Step 4
Develop decision model

Step 5
Test and review model: adequate performance?

Adjust, recalibrate

No

Yes

Calibrated BCG model with quantitative decision rules for assigning sample sites to BCG levels
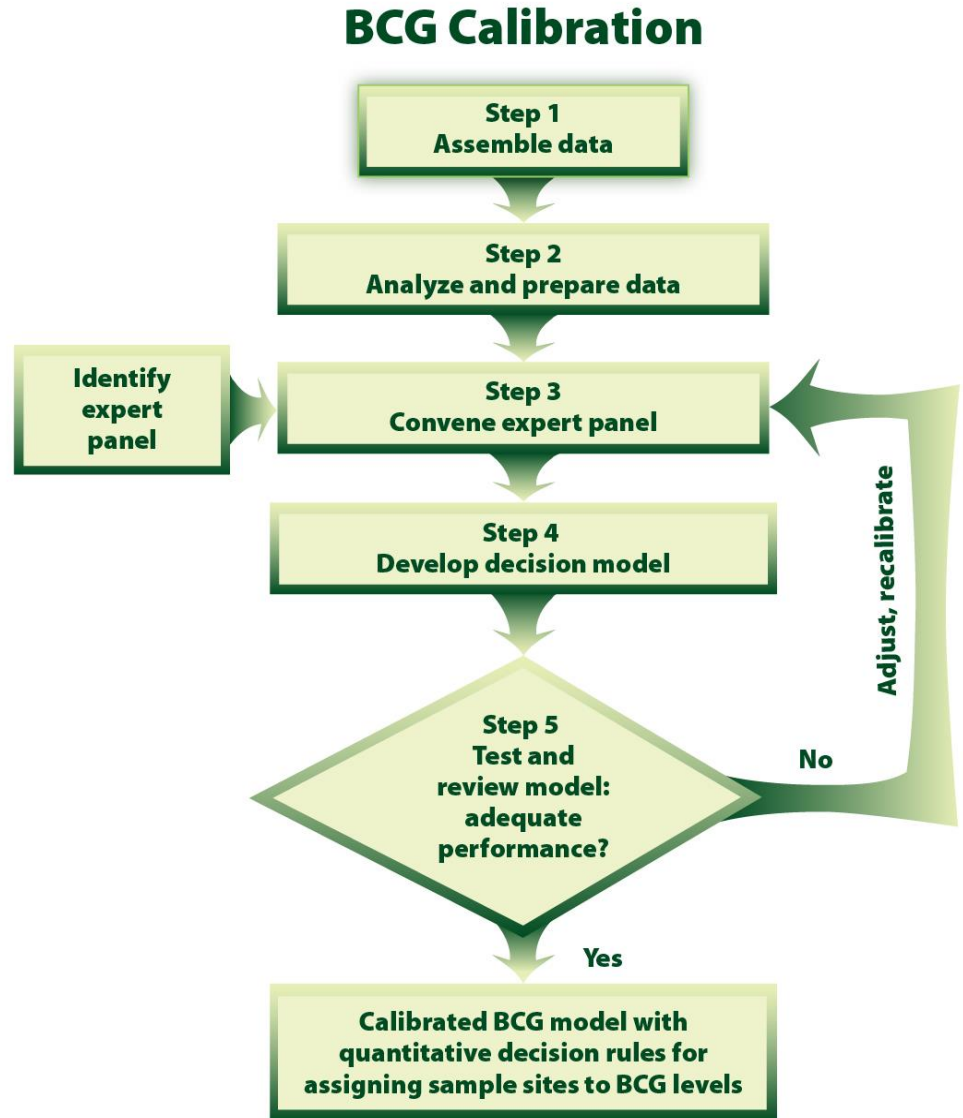
Assign Attributes

I. **Historically documented, sensitive, long-lived, regionally endemic taxa**

II. **Highly sensitive or specialist taxa**

III. **Sensitive and common taxa**

IV. **Taxa of intermediate tolerance**

V. **Tolerant taxa**

VI. **Non-native taxa**
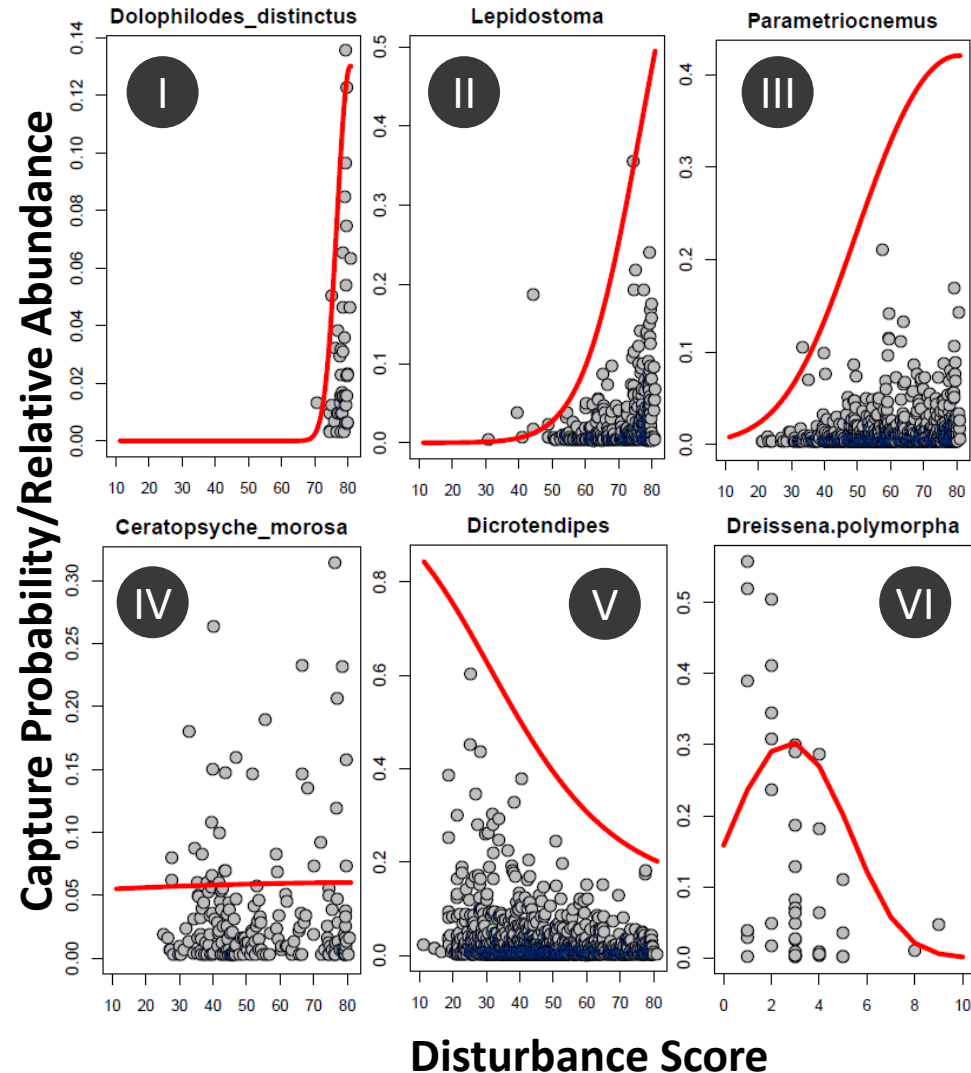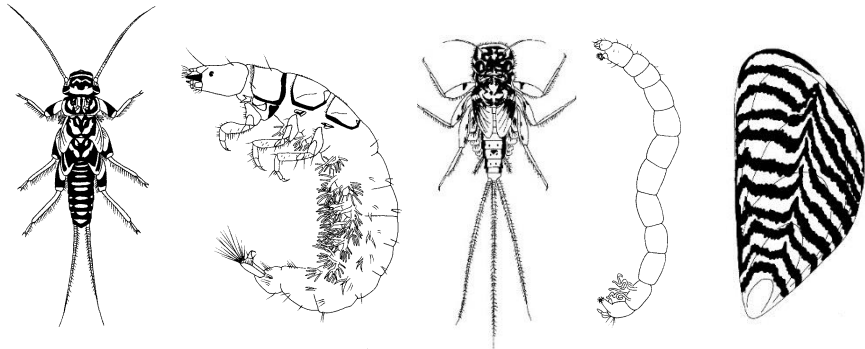
Assign BCG Levels

ExerciseID	Samp232	Assigned Tier	Reasoning			Go to StatusPage	ParticipantAssignments
Collection Method	HD	2-	y				
Collection Date	8/7/2003						

BCG Attribute	Number of Taxa	Num Ind	Pct Taxa	Pct Ind		Parameter	Value
1	0	0	0%	0%		Group Number	2
2	6	26	12%	5%		Group Name	Large Rivers
3	18	231	35%	43%		Watershed Area	
4	24	232	47%	43%		Gradient	0
5	0	0	0%	0%		GP/RR	GP
6	0	0	0%	0%		Disturbance Score	
x	3	45	6%	8%		Comments	0.0
Total	51	534					

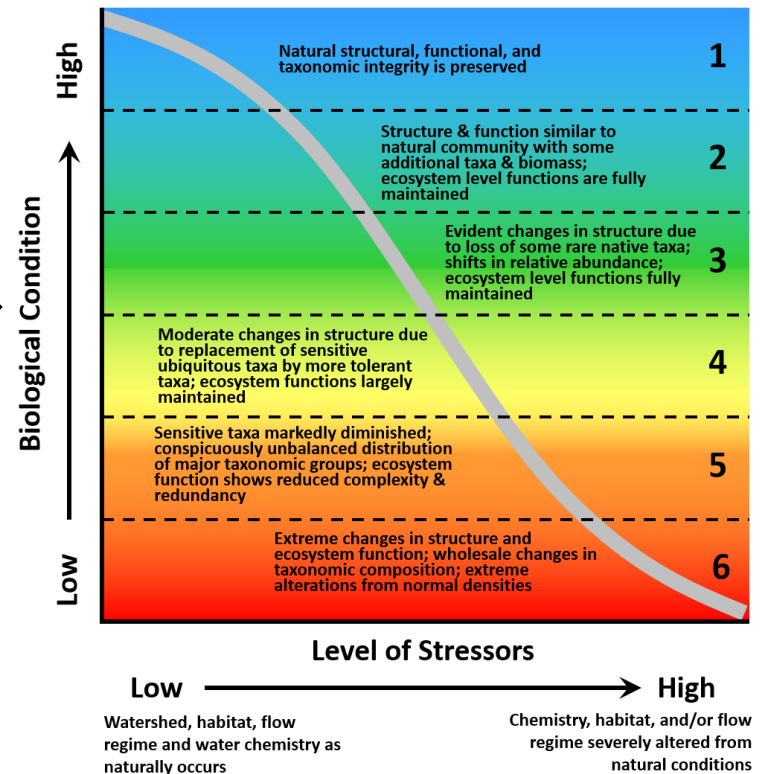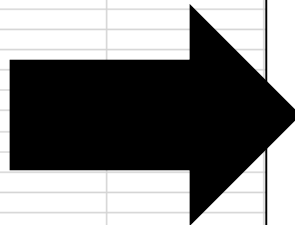| BCG Attribute	FinalID	Individuals	Order	Family (Tribe)
2	Laevapex	5	Basommatophora	Ancylidae
4	Dineutus	2	Coleoptera	Gyrinidae
3	Atherix variegata	1	Diptera	Athericidae
x	Chironomidae	6	Diptera	Chironomidae
x	Orthocladiinae	10	Diptera	Chironomidae
4	Chironomini	2	Diptera	Chironomidae(Chironomini)
3	Microtendipes	2	Diptera	Chironomidae(Chironomini)
4	Polypedilum	7	Diptera	Chironomidae(Chironomini)
3	Thienemanniella	4	Diptera	Chironomidae(Corynoneurini)
4	Cricotopus	4	Diptera	Chironomidae(Orthocladiini)
3	Eukiefferiella	2	Diptera	Chironomidae(Orthocladiini)
4	Nanocladius	5	Diptera	Chironomidae(Orthocladiini)
3	Orthocladius	2	Diptera	Chironomidae(Orthocladiini)
4	Rheocricotopus	5	Diptera	Chironomidae(Orthocladiini)
2	Synorthocladius	4	Diptera	Chironomidae(Orthocladiini)
3	Tvetenia	61	Diptera	Chironomidae(Orthocladiini)
3	Nilotanypus	1	Diptera	Chironomidae(Pentaneurini)
4	Rheotanytarsus	17	Diptera	Chironomidae(Tanytarsini)
2	Sublettea	3	Diptera	Chironomidae(Tanytarsini)
4	Tanytarsini	1	Diptera	Chironomidae(Tanytarsini)
3	Simulium	85	Diptera	Simuliidae(Prosimuliini)
3	Simulium jenningsi	2	Diptera	Simuliidae(Simuliini)
2	Antocha	1	Diptera	Tipulidae(Limoniini)
2	Acentrella turbida	3	Ephemeroptera	Baetidae
x	Baetidae	29	Ephemeroptera	Baetidae
3	Baetis	2	Ephemeroptera	Baetidae
2	Baetis flavistriga	10	Ephemeroptera	Baetidae
3	Baetis intercalaris	21	Ephemeroptera	Baetidae
3	Heterocloeon curiosum	12	Ephemeroptera	Baetidae
3	Plauditus	6	Ephemeroptera	Baetidae
3	Plauditus dubius	9	Ephemeroptera	Baetidae
4	Heptagenia	1	Ephemeroptera	Heptageniidae
4	Heptageniidae	10	Ephemeroptera	Heptageniidae
4	Maccaffertium	22	Ephemeroptera	Heptageniidae
3	Maccaffertium exiguum	5	Ephemeroptera	Heptageniidae
4	Isonychia	9	Ephemeroptera	Isonychiidae
4	Tricorythodes	3	Ephemeroptera	Leptohyphidae

High — **Low** — Biological Condition

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6 — Extreme changes in structure and ecosystem function; wholesale changes in taxonomic composition; extreme alterations from normal densities

Level of Stressors

Low ⟶ High

Low: Watershed, habitat, flow regime and water chemistry as naturally occurs

High: Chemistry, habitat, and/or flow regime severely altered from natural conditions

Develop Decision Rules

- Identify metrics
  - Information collected during BCG workshops
  - Analysis of metrics following workshops
- Types of metrics (% individuals, % taxa, # taxa)
  - Total taxa richness
  - Sensitive taxa (1+2+3 attribute taxa)
  - Taxa metrics (Ephemeroptera, Plecoptera, Trichoptera, EPT, brook trout)
  - Tolerant taxa (5+6 attribute taxa)
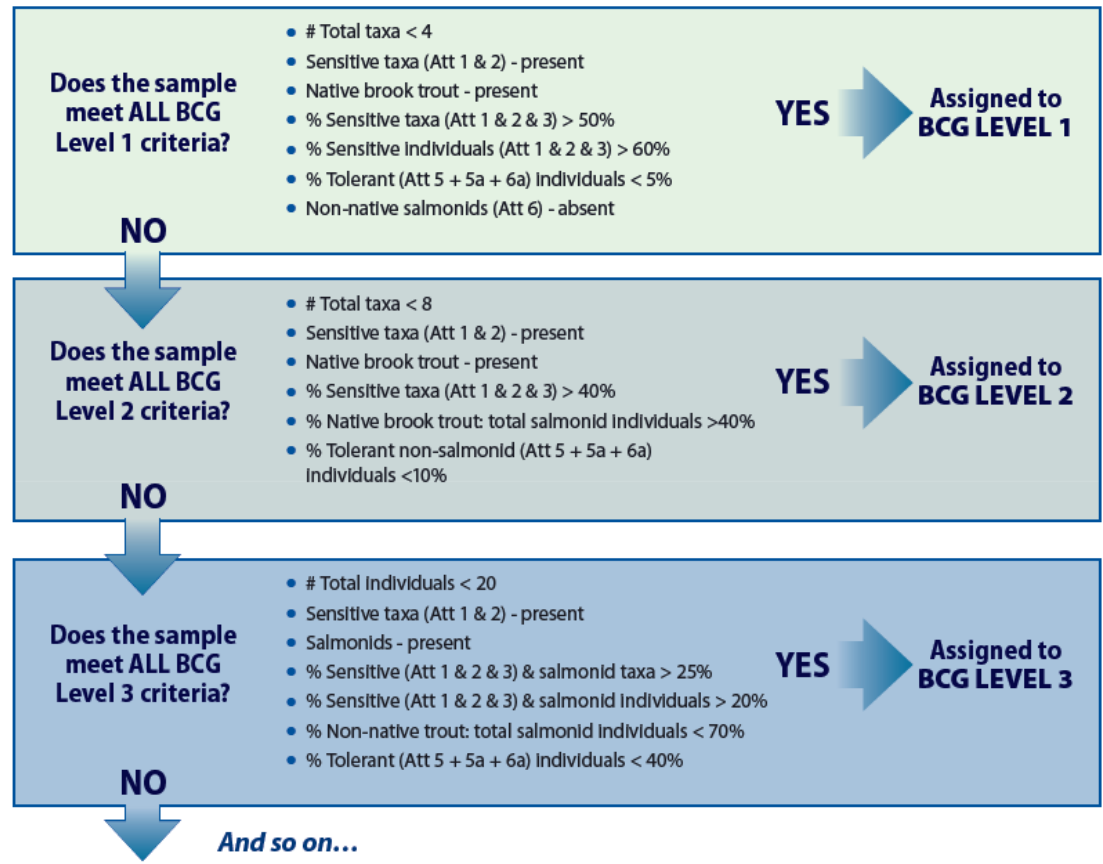 - % dominant (all taxa, tolerant taxa, attribute 4)

Metric Score

Panel BCG Score

Decision Rules
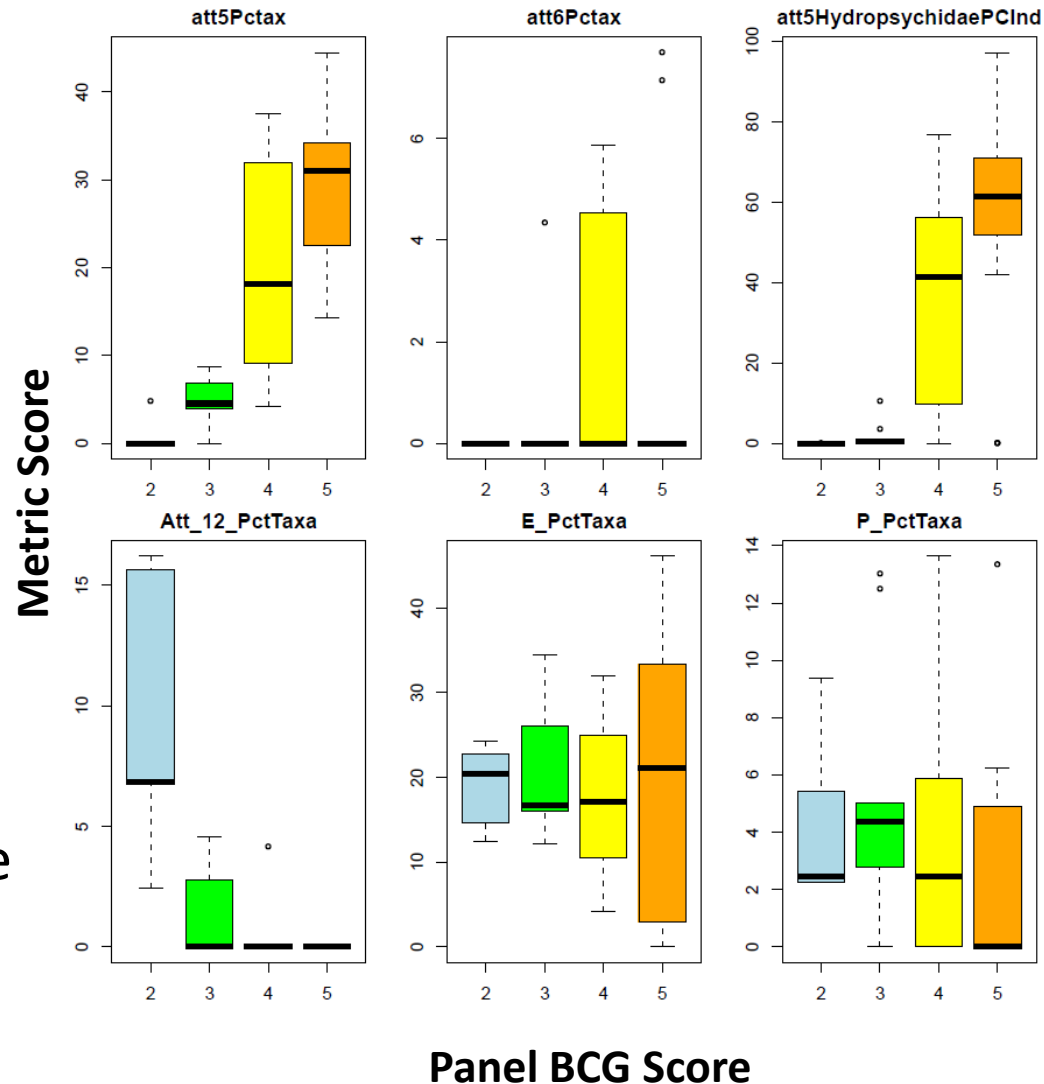
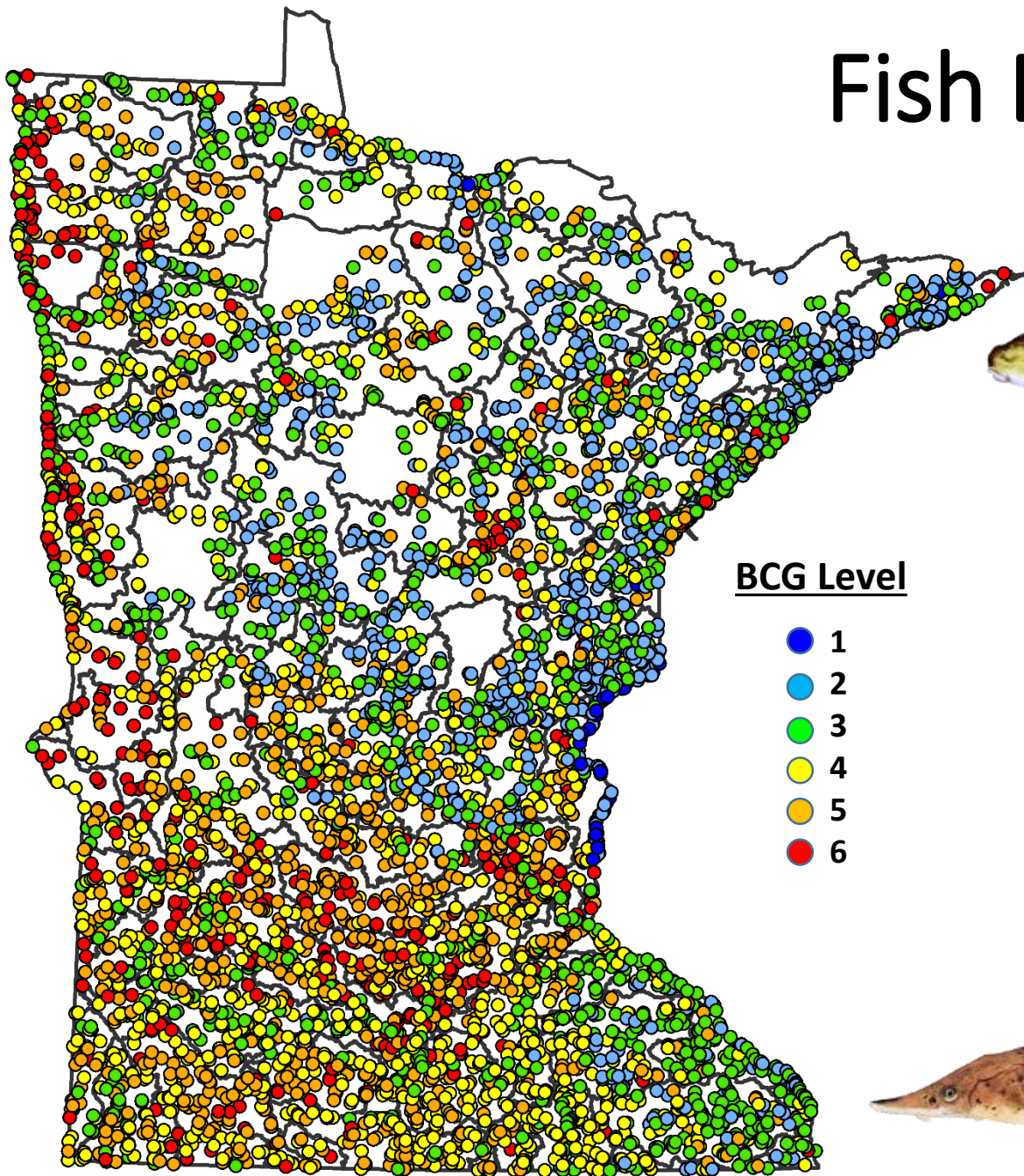| Metric	Rule
Level 1	
Total Taxa	<2-5
Att 1+2 Taxa	present
Brook Trout	present
Att 1+2+3 % Taxa	>45-55%
Att 1+2+3 % Ind	>55-65%
Att 5+5a+6a % Ind	<3-7%
Att 6 Ind	absent
Level 2	
Total Taxa	<6-10
Brook Trout	Present
Att 1+2+3 % Taxa	>35-45%
Brook Trout/Salmonids	>35-45%
Att 5+5a+6a % Ind	>7-13
Level 3	
Att 1+2+3+Salmonidae % Taxa	>20-30%
Att 1+2+3+Salmonidae % Ind	>15-25%
Salmonids	present
Att 4-5 Dom	<45-55%
Att 5+5a+6a % Ind	<7-13%
Level 4	
Att 1+2+3+6 % Taxa	3-7%
Att 1+2+3+6 % Ind	3-7%
Att 5+5a+6a % Taxa	<40-50%
Att 5a + 6a % Ind	<7-13%
Level 5	
Total Taxa	>1-4
Att 1+2+3+$ % Taxa	>7-13%

- Model developed using fuzzy set theory to replicate panel decisions

How does the BCG model work? *Like a cascade…*

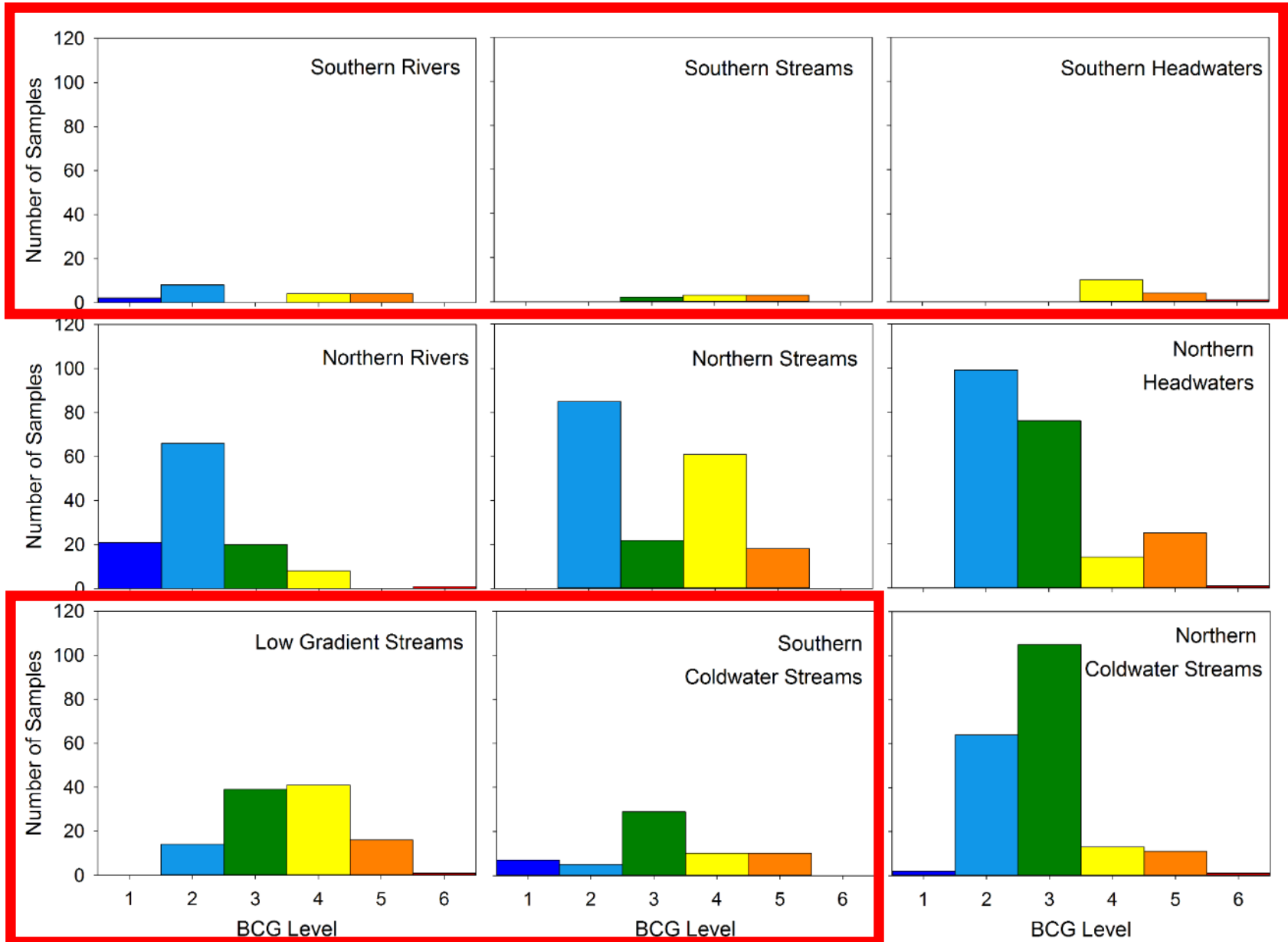Example: coldwater sample from site where watershed size is ≤ 10 mi^2 and brook trout are native*

Does the sample meet ALL BCG Level 1 criteria?
- # Total taxa < 4
- Sensitive taxa (Att 1 & 2) - present
- Native brook trout - present
- % Sensitive taxa (Att 1 & 2 & 3) > 50%
- % Sensitive individuals (Att 1 & 2 & 3) > 60%
- % Tolerant (Att 5 + 5a + 6a) individuals < 5%
- Non-native salmonids (Att 6) - absent

YES → Assigned to **BCG LEVEL 1**

NO

Does the sample meet ALL BCG Level 2 criteria?
- # Total taxa < 8
- Sensitive taxa (Att 1 & 2) - present
- Native brook trout - present
- % Sensitive taxa (Att 1 & 2 & 3) > 40%
- % Native brook trout: total salmonid individuals >40%
- % Tolerant non-salmonid (Att 5 + 5a + 6a) individuals <10%

YES → Assigned to **BCG LEVEL 2**

NO

Does the sample meet ALL BCG Level 3 criteria?
- # Total Individuals < 20
- Sensitive taxa (Att 1 & 2) - present
- Salmonids - present
- % Sensitive (Att 1 & 2 & 3) & salmonid taxa > 25%
- % Sensitive (Att 1 & 2 & 3) & salmonid individuals > 20%
- % Non-native trout: total salmonid individuals < 70%
- % Tolerant (Att 5 + 5a + 6a) individuals < 40%

YES → Assigned to **BCG LEVEL 3**

NO

And so on…

Fish BCG Scores
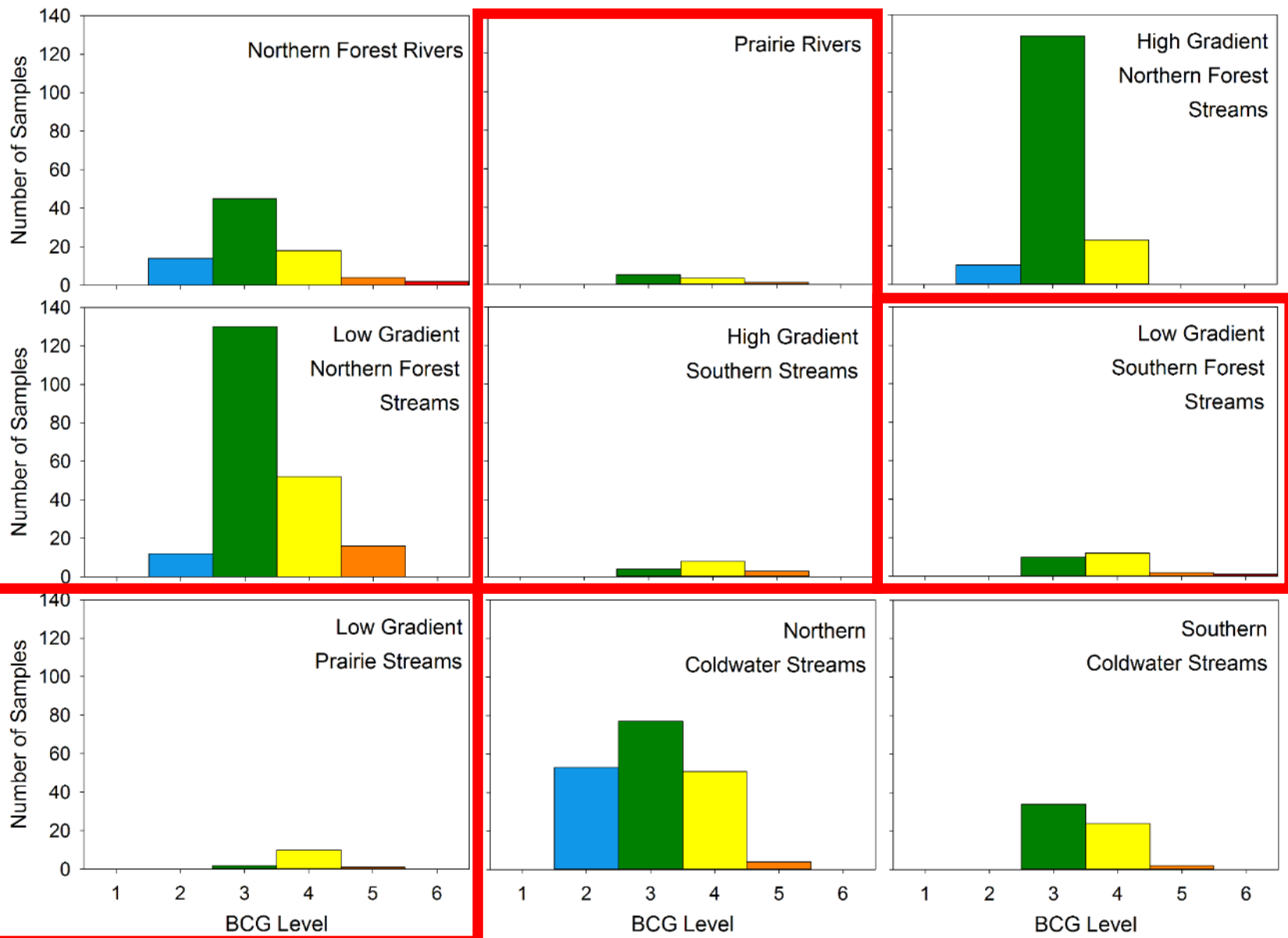

BCG Level

- 🔵 1
- 🔵 2
- 🟢 3
- 🟡 4
- 🟠 5
- 🔴 6

Reference Site BCG Scores - Fish

Reference Site BCG Scores - Inverts

BCG and Reference Condition

1 — Natural structural, functional, and taxonomic integrity is preserved

2 — Structure & function similar to natural community with some additional taxa & biomass; ecosystem level functions are fully maintained

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4 — Moderate changes in structure due to replacement of sensitive ubiquitous taxa by more tolerant taxa; ecosystem functions largely maintained

5 — Sensitive taxa markedly diminished; conspicuously unbalanced distribution of major taxonomic groups; ecosystem function shows reduced complexity & redundancy

6 — Extreme changes in structure and ecosystem function; wholesale changes in taxonomic composition; extreme alterations from normal densities

Biological Condition — High / Low

Northern Rivers

Low-Gradient Streams

Southern Headwaters

Minimally Disturbed

Least Disturbed

Least Disturbed

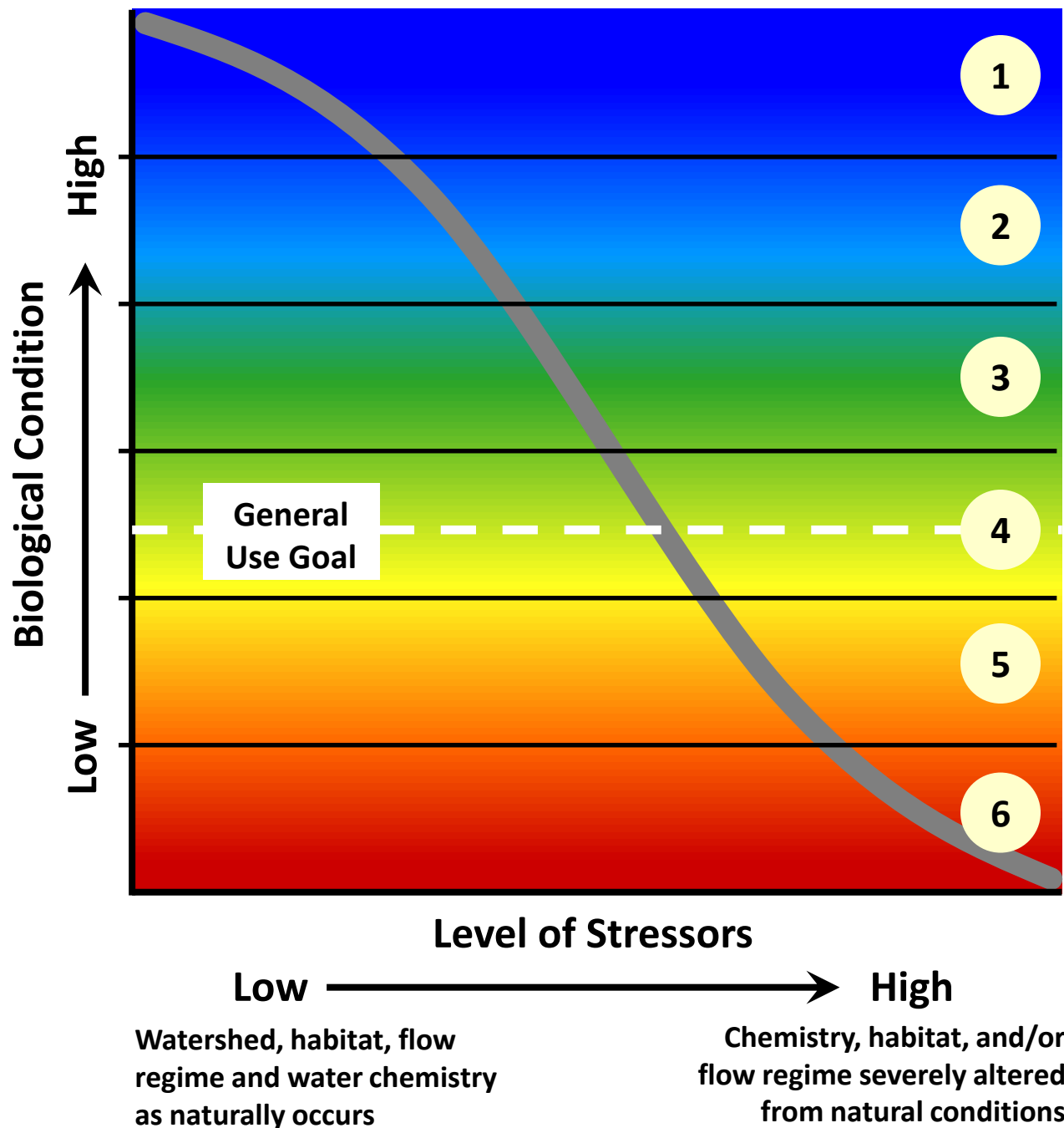Level of Exposure to Stressors — Low → High

Translating the BCG to Goals

BCG Level 4:
"Moderate changes in structure due to replacement of sensitive ubiquitous taxa by more tolerant taxa; ecosystem functions largely maintained"

Bouchard et al. (2016) *Environmental Monitoring and Assessment* 188(3): 1-26.

1	**Natural structural, functional, and taxonomic integrity is preserved**
2	**Structure & function similar to natural community with some additional taxa & biomass; ecosystem level functions are fully maintained**
3	**Evident changes in structure due to loss of some rare native taxa; shifts in relative abundance; ecosystem level functions fully maintained**
4	**Moderate changes in structure due to replacement of sensitive ubiquitous taxa by more tolerant taxa; ecosystem functions largely maintained**
5	**Sensitive taxa markedly diminished; conspicuously unbalanced distribution of major taxonomic groups; ecosystem function shows reduced complexity & redundancy**
6	**Extreme changes in structure and ecosystem function; wholesale changes in taxonomic composition; extreme alterations from normal densities**

Biological Condition

High

Low

1

2

3

General Use Goal

4

5

6

Level of Stressors

Low ⟶ **High**

Watershed, habitat, flow regime and water chemistry as naturally occurs

Chemistry, habitat, and/or flow regime severely altered from natural conditions

Macroinvertebrates: Overall taxa richness and density is as naturally occurs. Most sensitive (Attribute II) taxa (e.g. *Trichoptera*: **Glossosoma, Rhyacophila, Lepidostoma, Dolophilodes;** *Ephemeroptera*: **Ephemerella, Epeorus;** *Plecoptera**: Leuctridae*) and other taxa must be present. These plus intermediate sensitive (Attribute III) taxa (e.g., *Ephemeroptera*: **Paraleptophlebia**; *Plecoptera*: **Acroneuria, Isoperla, Paragnetina**; *Trichoptera*: **Brachycentrus, Chimarra**) occur in higher relative abundances than in BCG level 3 samples. Tolerant taxa occur in low numbers.

Ecosystem level functions fully maintained, but *some changes taxa and biomass*

BCG Level 2

One-size-fits-all Goals

W. Br. Little Knife River

Little Cedar River

Judicial Ditch 7

Tiered Aquatic Life Uses
More Precise Aquatic Life Goals

W. Br. Little Knife River

Little Cedar River

Judicial Ditch 7

Exceptional Use
High quality water resources

General Use
"Protection and propagation of fish, shellfish and wildlife"

Modified Use
Water resources with human altered habitat

75th Percentile Reference Sites/
75th Percentile of BCG3 Sites

25th Percentile Reference Sites/
Median of BCG4 Sites

25th Percentile "Modified" Reference Sites/
Median of BCG5 Sites

Biological Criteria Calibration

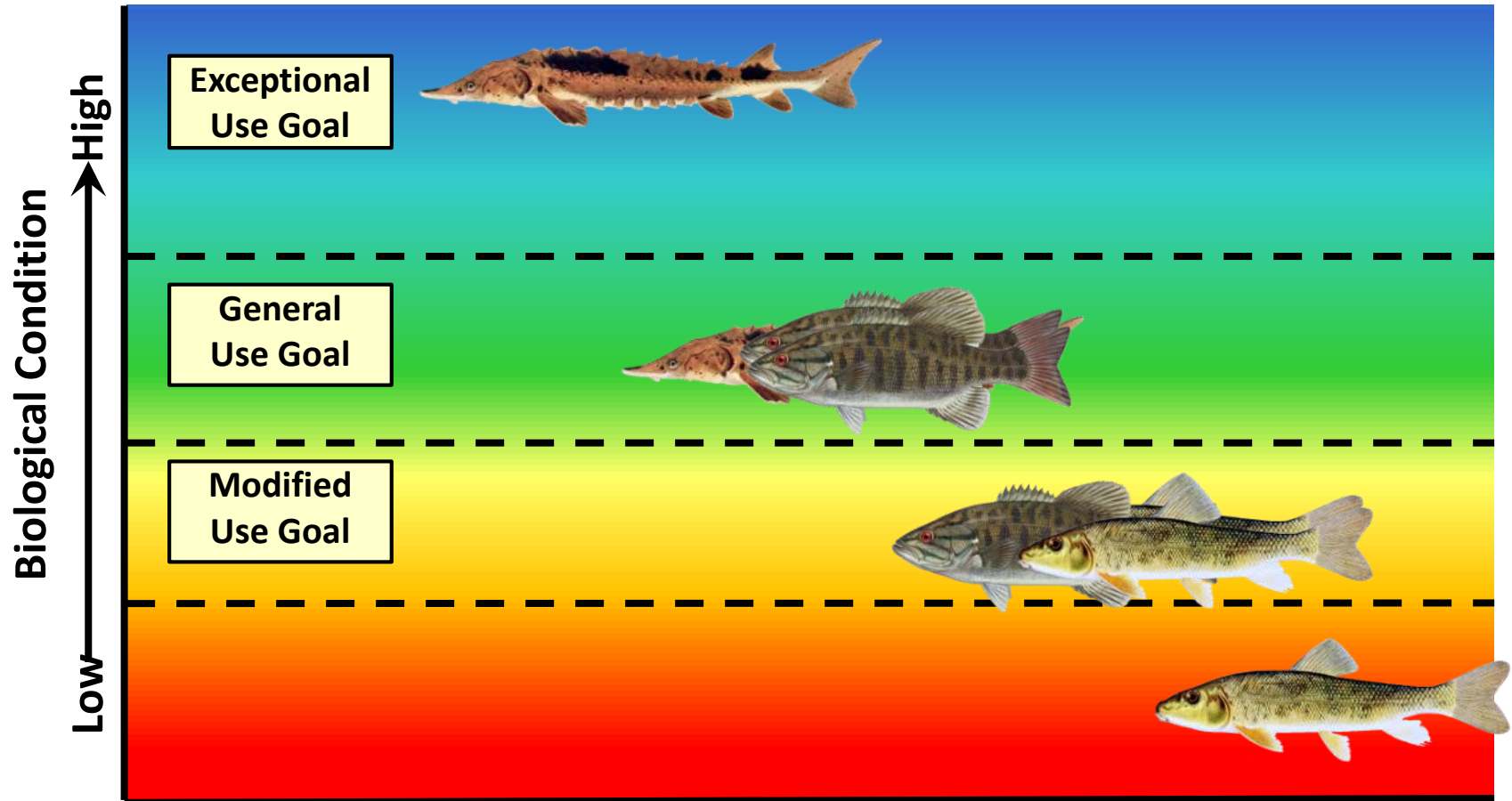| Stream Type	Exceptional Use	General Use	Modified Use
Fish			
Southern Rivers	71	49	
Southern Streams	66	50	35
Southern Headwaters	74	55	33
Northern Rivers	67	38	
Northern Streams	61	47	35
Northern Headwaters	68	42	23
Low Gradient Streams	70	42	15
Southern Coldwater	82	50	
Northern Coldwater	60	35	
Macroinvertebrates			
Northern Forest Rivers	77	49	
Prairie and Southern Forest Rivers	63	31	
Northern Forest Streams High Gradient	82	53	
Northern Forest Streams Low Gradient	76	51	37
Southern Streams High Gradient	62	37	24
Southern Forest Streams Low Gradient	66	43	30
Prairie Streams Low Gradient	69	41	22
Northern Coldwater	52	32	
Southern Coldwater	72	43	

Tiered biological criteria adopted into Minnesota rules October 2017

The BCG and Biocriteria

- Linking biocriteria to the BCG provides narratives linked to ecological theory:

  - **<u>Exceptional Use:</u>** *"Structure & function similar to natural community with some additional taxa and biomass; ecosystem level functions are fully maintained"*

  - **<u>General Use:</u>** *"Overall balanced distribution of all expected major groups" with "ecosystem functions largely maintained through redundant attributes"*

  - **<u>Modified Use:</u>** *"Sensitive taxa markedly diminished; conspicuously unbalanced distribution of major taxonomic groups; ecosystem function shows reduced complexity and redundancy"*

Aquatic Life Use Goals

Biological Condition (High → Low)

Exceptional Use Goal

General Use Goal

Modified Use Goal

Determining Tiered Uses

Does the stream meet the General or Exceptional Use biological criteria?

Biological Criteria

Stream Type	Exceptional Use	General Use	Modified Use
Fish			
Southern Rivers	71	49	
Southern Streams	66	50	35
Southern Headwaters	74	55	33
Northern Rivers	67	38	
Northern Streams	61	47	35
Northern Headwaters	68	42	23
Low Gradient Streams	70	42	15
Southern Coldwater	82	50	
Northern Coldwater	60	35	
Macroinvertebrates			
Northern Forest Rivers	77	49	
Prairie and Southern Forest Rivers	63	31	
Northern Forest Streams High Gradient	82	53	
Northern Forest Streams Low Gradient	76	51	37
Southern Streams High Gradient	62	37	24
Southern Forest Streams Low Gradient	66	43	30
Prairie Streams Low Gradient	69	41	22
Northern Coldwater	52	32	
Southern Coldwater	72	43	

Determining Tiered Uses

Does the stream meet the General or Exceptional Use biological criteria?

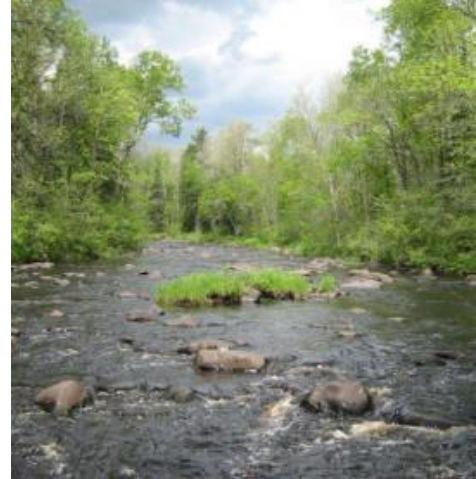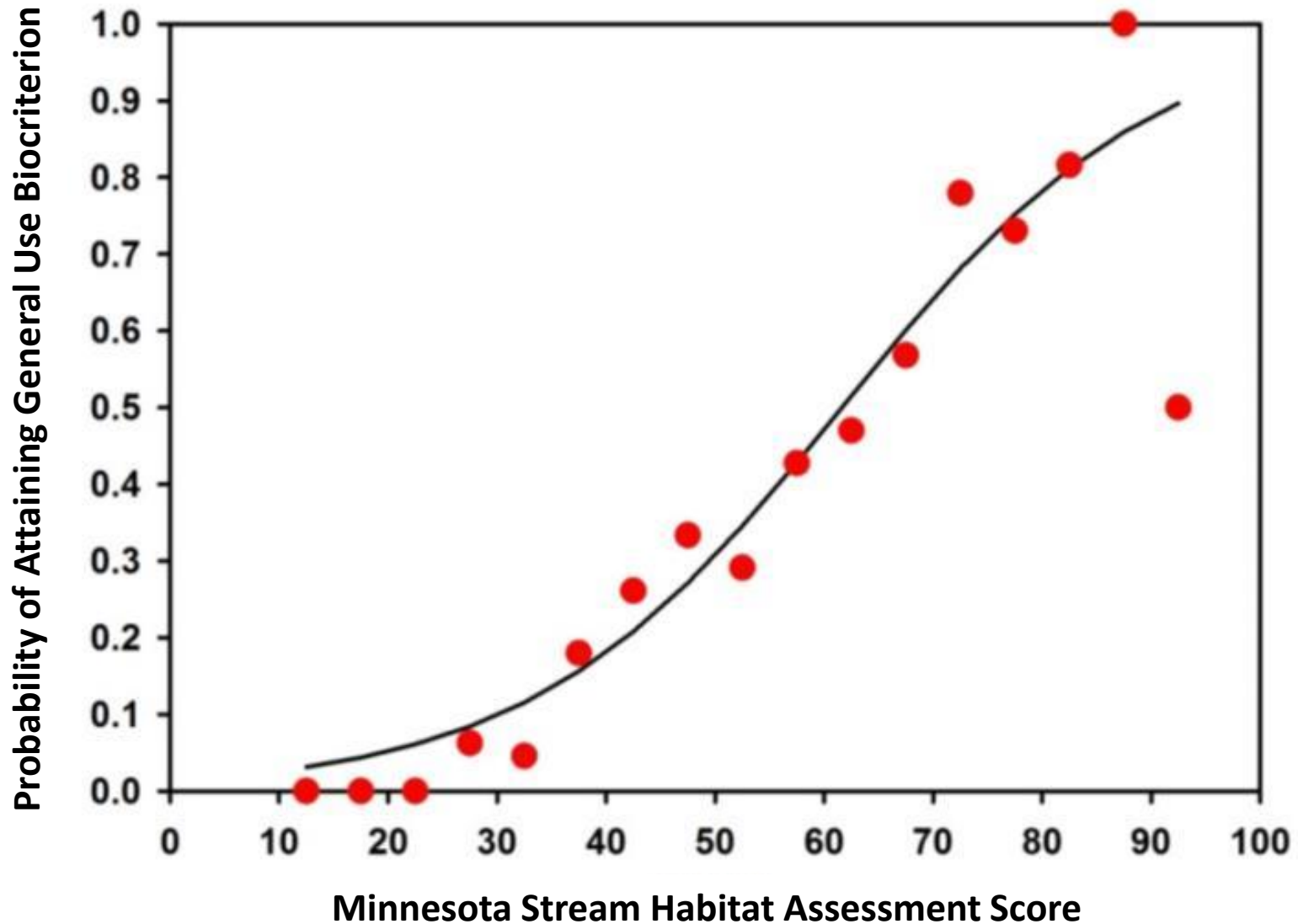**YES** → **Designate General or Exceptional Use**

Use Attainability Analysis

NO

Is habitat limiting the biological communities?

Habitat Predictive models

Probability of Attaining General Use Biocriterion (y-axis)

Minnesota Stream Habitat Assessment Score (x-axis)

Determining Tiered Uses

Does the stream meet the General or Exceptional Use biological criteria? → **YES** → **Designate General or Exceptional Use**

- -

Use Attainability Analysis

NO ↓

Is habitat limiting the biological communities? → **NO** → **Designate General Use**

YES ↓

Is the limiting habitat the result of legal human activities? → **NO** → **Designate General Use**

YES ↓

The stream is eligible for Modified Use designation

General Uses

Biology Meets General Use Goals

Habitat Not Limiting

General Use Ditches

Restorable
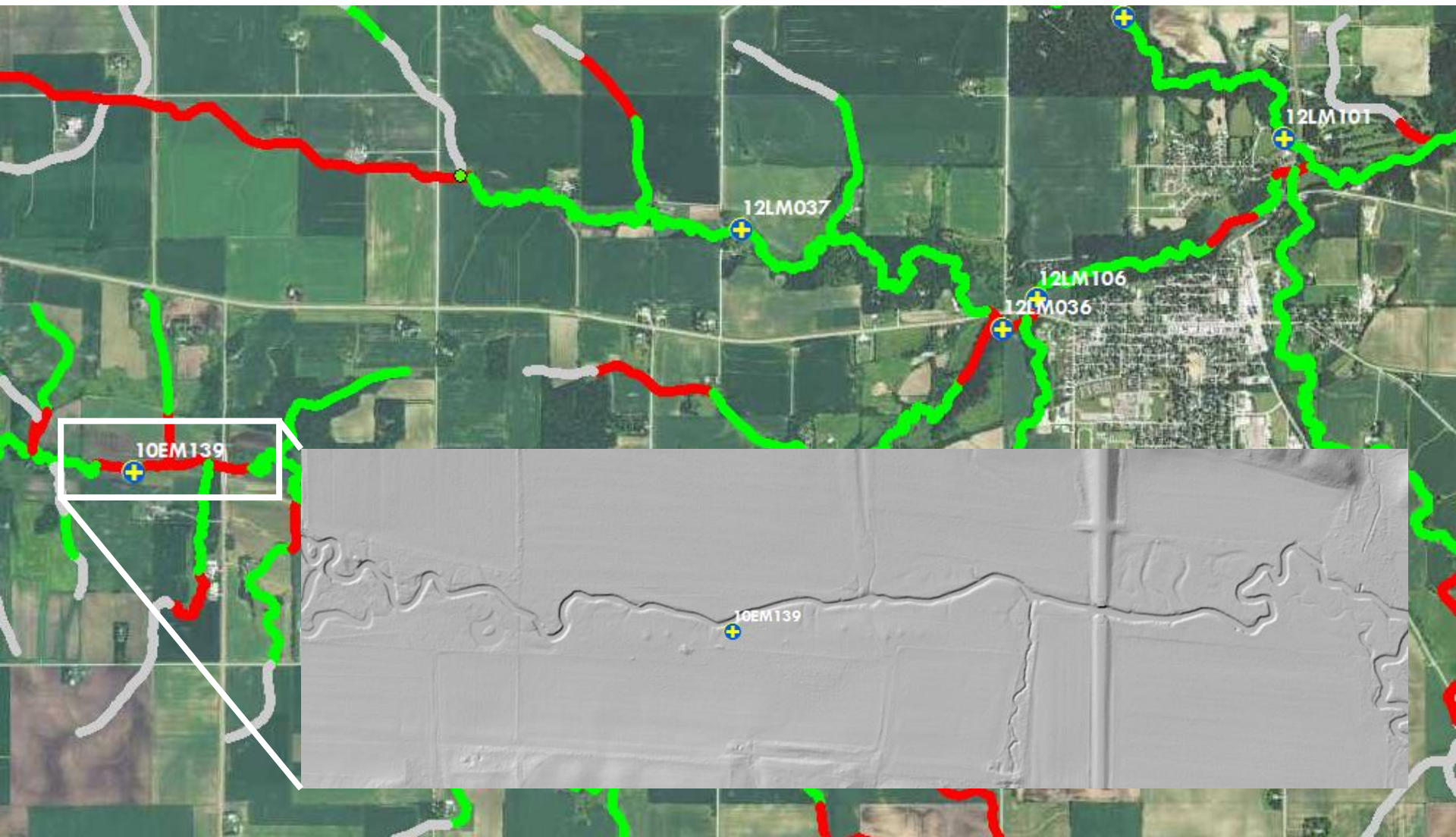
Existing Use = General Use

07100001-619 Unnamed Creek

01-June-1976

14D M046

Modified Use
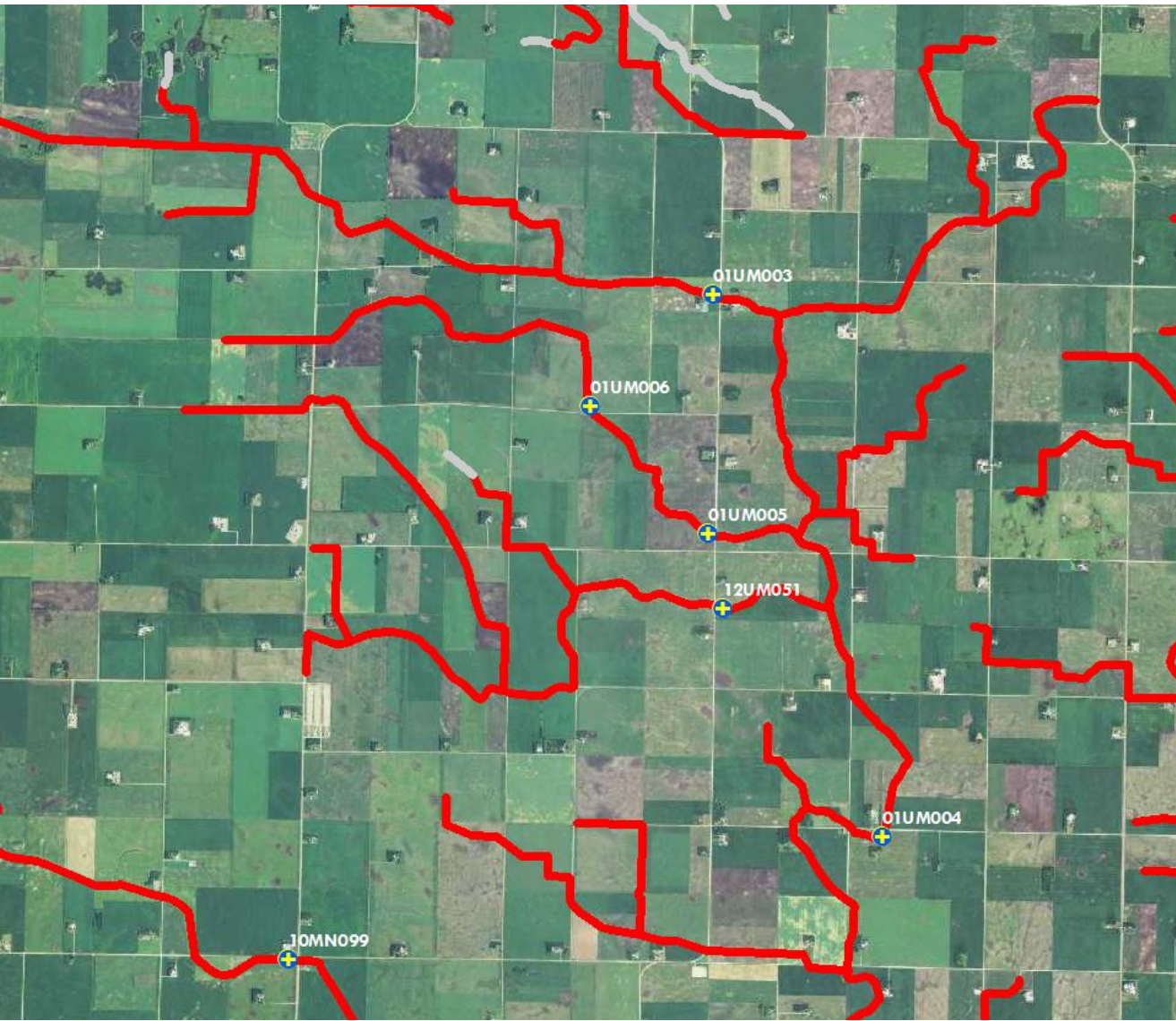
Tiered Aquatic Life Uses
More Precise Aquatic Life Goals

W. Br. Little Knife River

Exceptional Use
High quality water resources

Little Cedar River

General Use
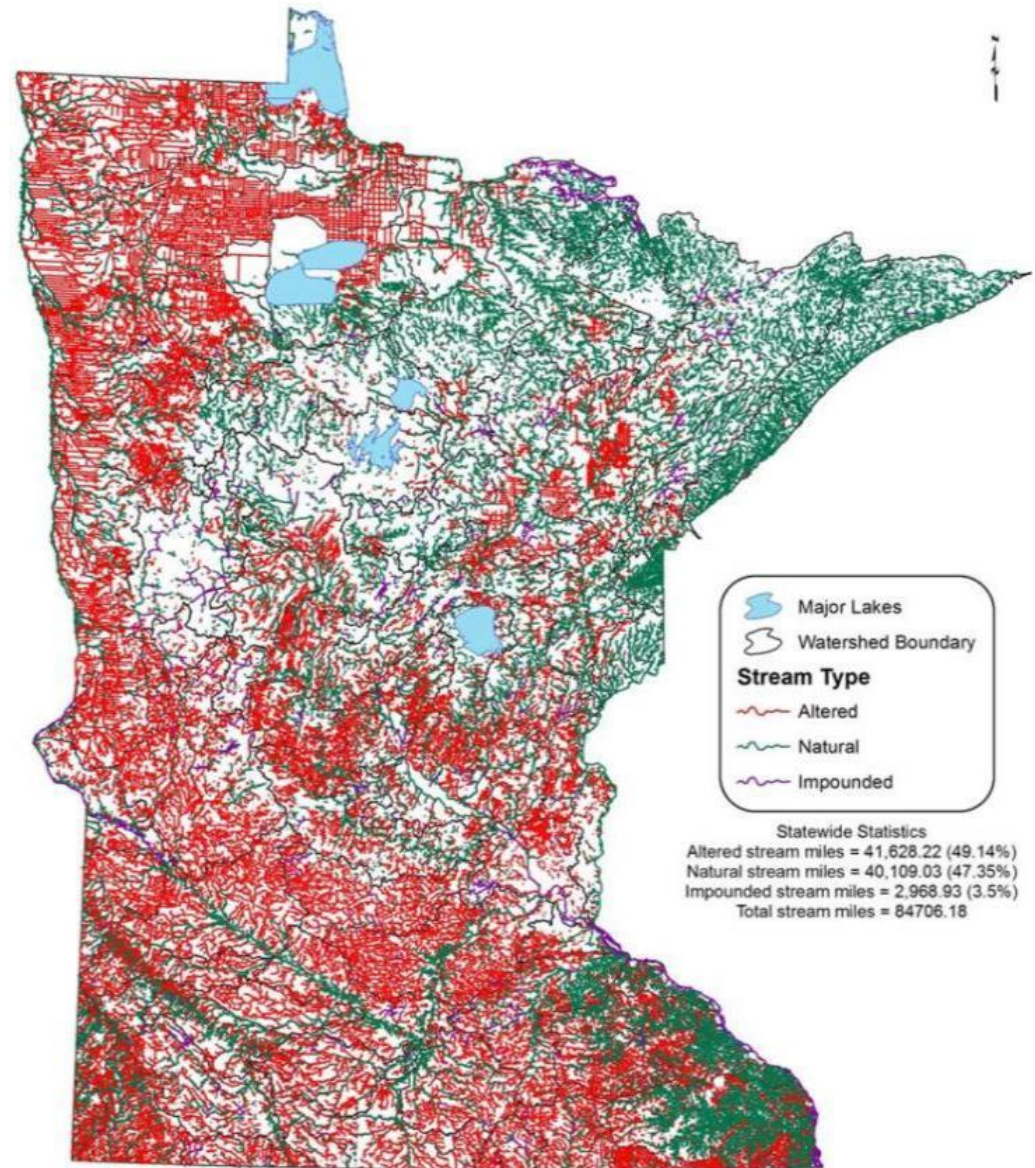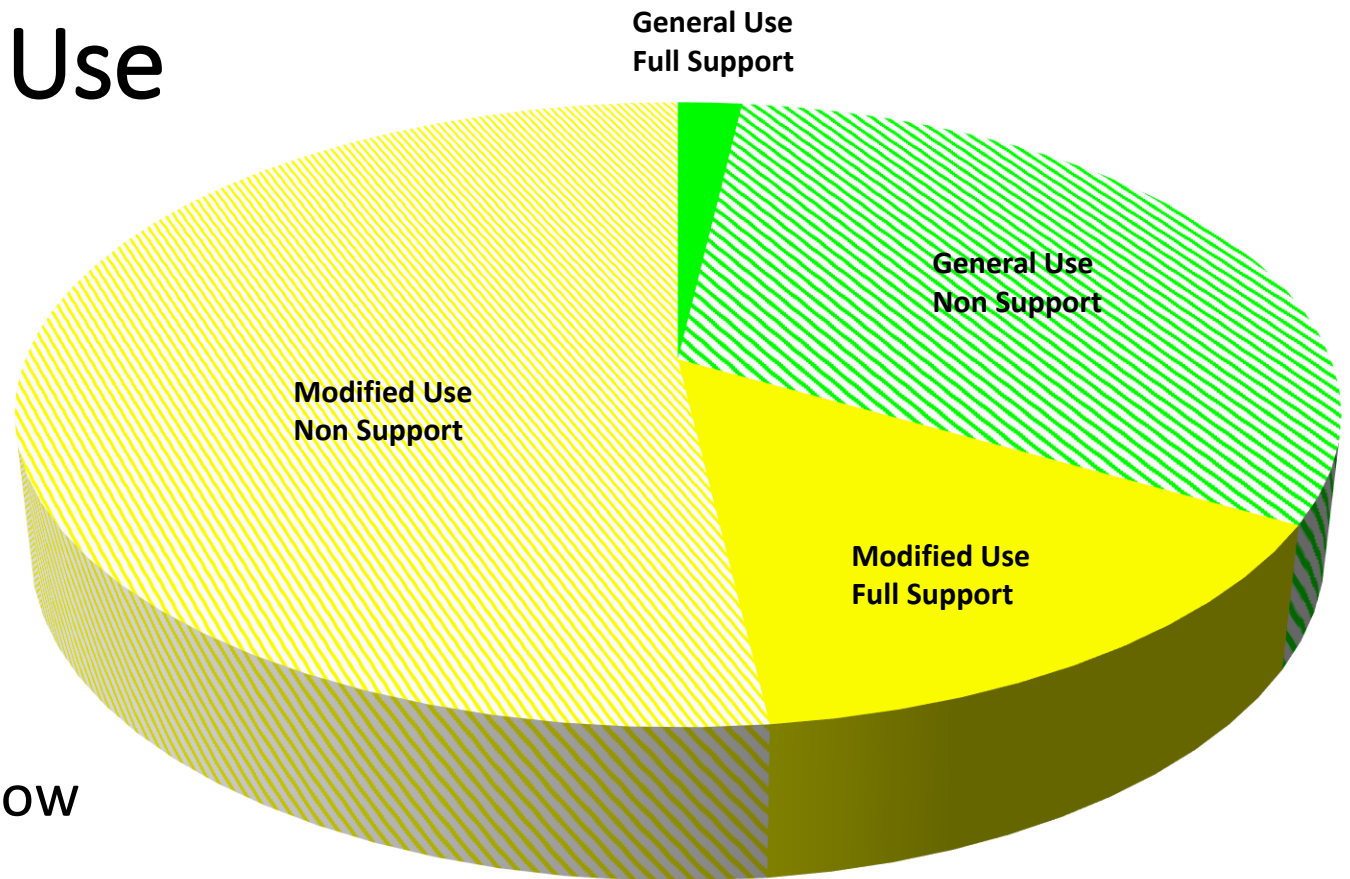"Protection and propagation of fish, shellfish and wildlife"

Judicial Ditch 7

Modified Use
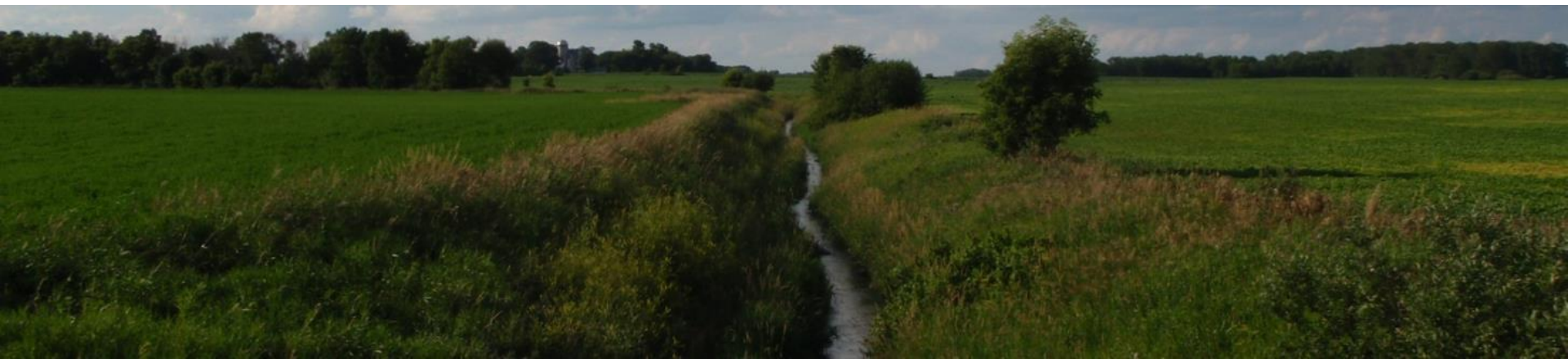Water resources with human altered habitat

Modified Use Implications

- Fewer impaired waters
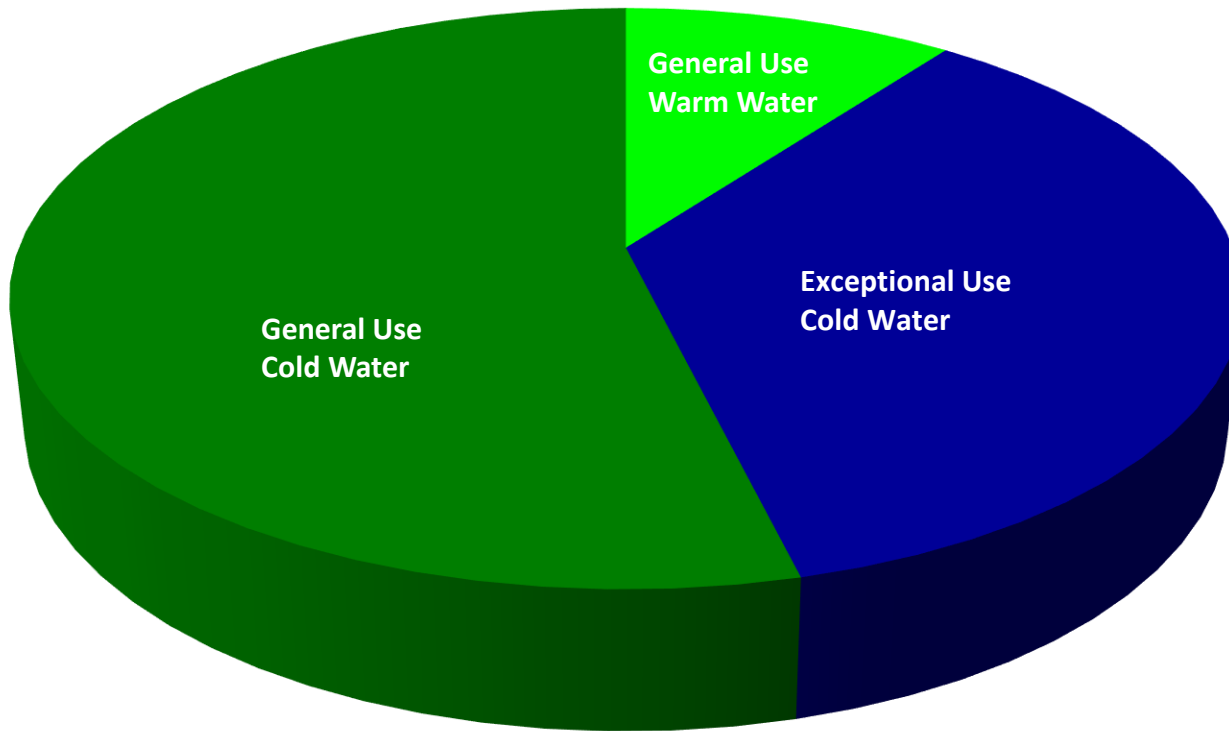- When Modified Use streams are impaired, attainable goals are set

Major Lakes
Watershed Boundary
Stream Type
Altered
Natural
Impounded

Statewide Statistics
Altered stream miles = 41,628.22 (49.14%)
Natural stream miles = 40,109.03 (47.35%)
Impounded stream miles = 2,968.93 (3.5%)
Total stream miles = 84706.18

Modified Use Waters

South Fork Crow
Watershed

Exceptional Use Waters

Pie chart with the following segments:
- General Use Warm Water
- Exceptional Use Cold Water
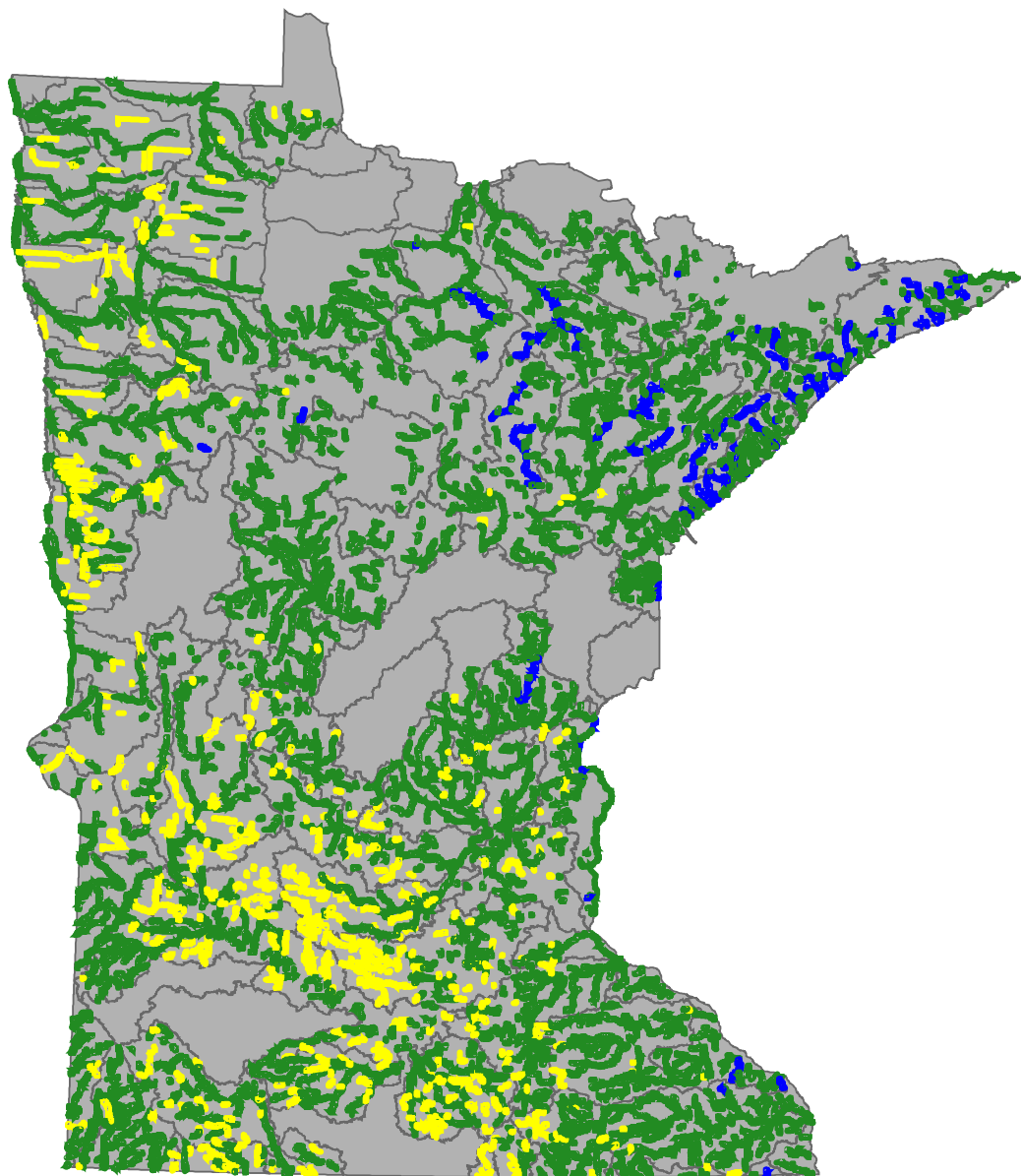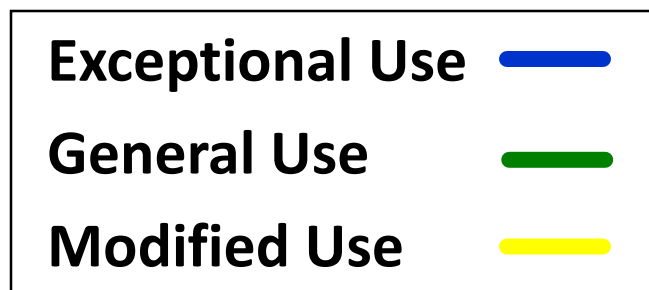- General Use Cold Water

Lake Superior – North Watershed

- Exceptional Use needs to be maintained
- Protection implemented through WRAPS, antidegradation, and site-specific standards
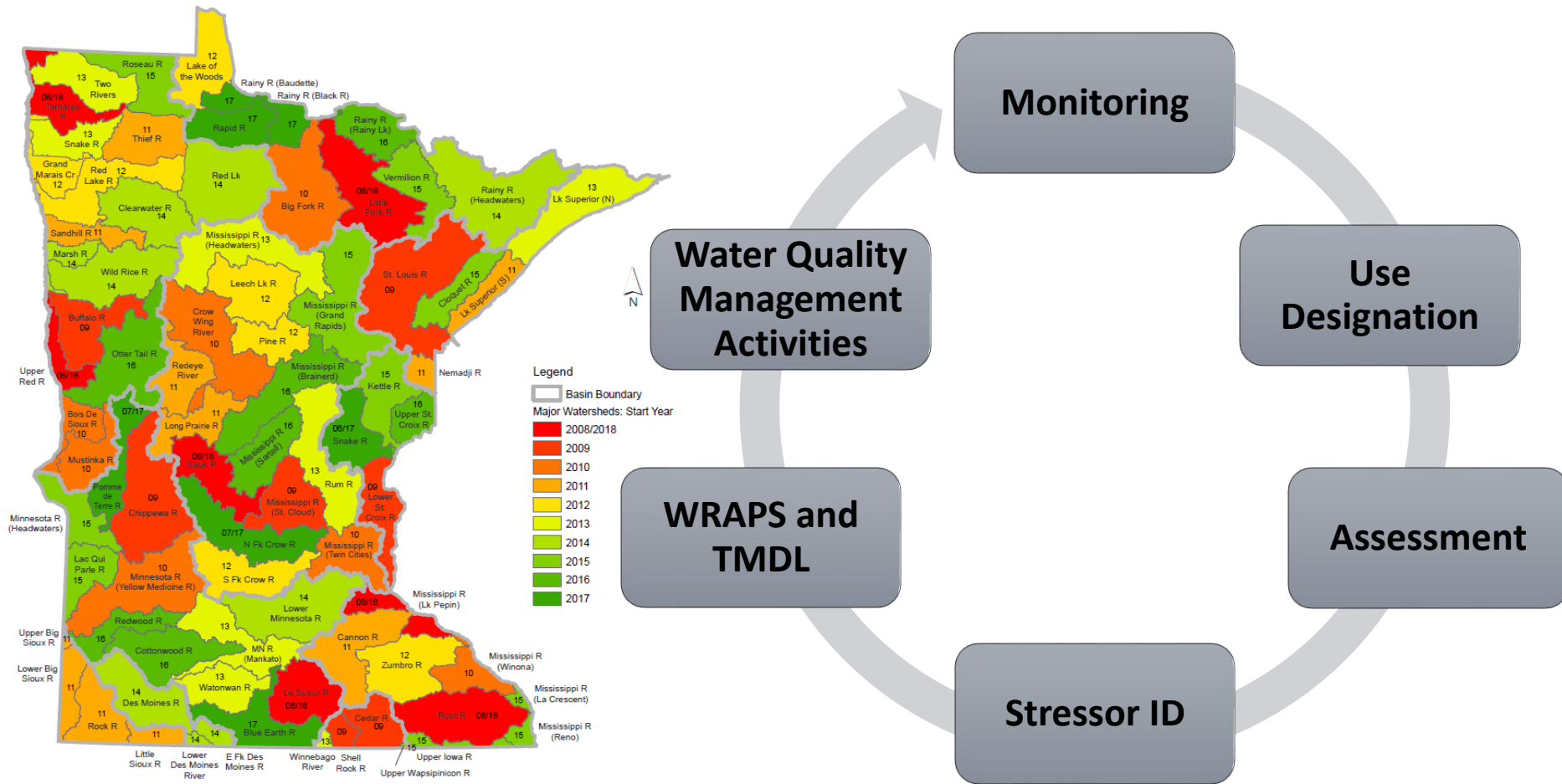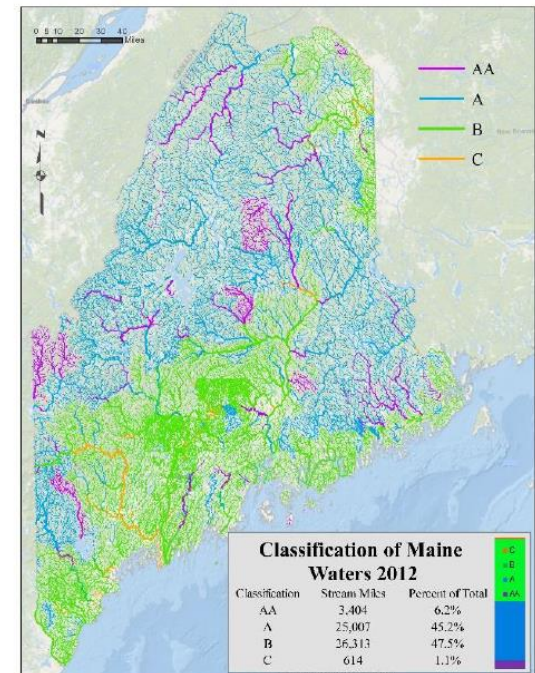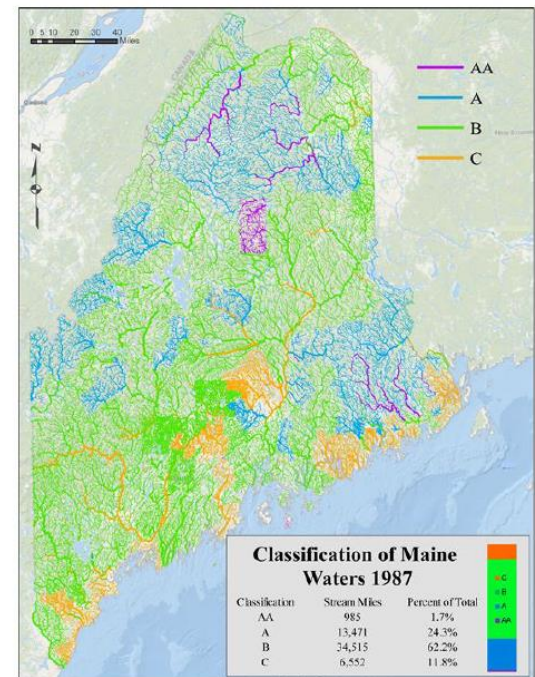
Preliminary Tiered Aquatic Life Use Determinations

Legend:
- **Exceptional Use** — blue
- **General Use** — green
- **Modified Use** — yellow

Intensive Watershed Management Strategy

10 Year Cycle

TALU Outcomes

- Full attainment of aquatic life use goals for Ohio watersheds increased from 46.6% in 2002 to 59.2% in 2014

- Maine has documented a 25.5% increase in the stream miles assigned to Maine's highest aquatic life use class

Classification of Maine Waters 1987

Classification	Stream Miles	Percent of Total
AA	985	1.7%
A	13,471	24.3%
B	34,515	62.2%
C	6,552	11.8%

Classification of Maine Waters 2012

Classification	Stream Miles	Percent of Total
AA	3,404	6.2%
A	25,007	45.2%
B	26,313	47.5%
C	614	1.1%

The BCG and Biocriteria

- BCG provides a "yardstick" to compare biological condition across stream types, regions, states, etc.

- Set protective and consistent TALU biocriteria across Minnesota (especially useful for regions with widespread disturbance)

- Communicate biological goals

MINNESOTA POLLUTION CONTROL AGENCY

https://www.pca.state.mn.us/talu

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